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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

PROGRAMME OF THE

1955 MARCH MEETING

AT

BALTIMORE, MARYLAND

March 17–18–19, 1955

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March 17, 1955 Vol. 30, No. 2

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1955 MARCH MEETING AT BALTIMORE, MARYLAND, MARCH 17–19, 1955

THE **1955 March meeting of the American Physical Society** will be held at Baltimore, Maryland, on Thursday, Friday, and Saturday, March 17, 18, and 19, 1955. Owing to the proximity of Washington, we seldom meet in Baltimore; this is an injustice to an interesting and hospitable city. The sessions of Thursday, of Friday, and of the morning of Saturday will be held in the Lord Baltimore Hotel. The sessions of Saturday afternoon will be held at The Johns Hopkins University, partly for the convenience of the hotel, but mostly because it would be a shame for our members to go to Baltimore and fail to visit this great University. Information as to how to get to the University will be made available at the registration desk. The Chairman of the Local Committee is G. H. Dieke.

Hotel. All of our members are asked to stay at the Lord Baltimore Hotel, which is putting its halls at our disposition gratuitously for most of our sessions. Write at once to the hotel, mentioning that you are coming for the meeting of the Society. Room rates run from $5.50 to $10.50 for singles, from $8 to $13.50 for doubles with double bed, from $9 to $15 for doubles with twin beds: we are assured that there will be a copious supply in the lower price brackets.

The **registration desk** will be located in the Lord Baltimore Hotel. Our members and guests are asked to register, to pay the registration fee of one dollar, and to consult the nearby bulletin boards from time to time for notice of messages, post-deadline papers, and other information.

Our **Division of High-Polymer Physics** has adopted the March meeting as its principal meeting of the year. On this occasion it has organized a Symposium on the biophysics of nucleic acid (Thursday morning and afternoon) and has provided six other invited papers, not to speak of the contributed papers in this field. The names of the speakers will be found in the Epitome and the full titles in the main text of this Bulletin.

Our **Division of Solid-State Physics** also has adopted the March meeting as its principal meeting of the year. For this occasion it has organized symposia on spin-orbit effects in solids (Friday morning) and the physics of silver halides (Friday afternoon) and has provided four other invited papers. The names of the speakers will be found in the Epitome and the full titles in the main text of this Bulletin.

On the **general programme** we have the **Oliver E. Buckley address,** to be given on Saturday morning by LeRoy Apker, recipient of the 1955 Oliver E. Buckley Solid-State Physics Prize which will have been awarded at the 1955 Annual Meeting. J. H. Van Vleck will speak on paramagnetism in solids, and session (U) will comprise invited papers by J. H. Donnay and G. H. Dieke of The Johns Hopkins University. The University has also provided four invited papers in nuclear and atomic physics, to be given on Thursday morning by C. D. Swartz, G. E. Owen, S. S. Hanna, and J. A. Bearden.

Two hundred and one contributed papers are distributed among twenty sessions. This is about the same number as we had at the two previous March meetings. This suggests that the size of the March meeting is an invariant with respect to space and time. The attention of theoretical physicists is directed to this fact.

The **banquet of the Americal Physical Society** will be held on Friday evening at seven, in the Calvert Ballroom of the Lord Baltimore Hotel. At this banquet we shall have an event unprecedented at our meetings: the **award of the John Scott Medal and premium** to our members, Walter H. Brattain and John Bardeen, "for the invention of the transistor." The origin of this award is remarkable. John Scott was a chemist of Edinburgh, Scotland,

who in 1816 established the award and entrusted the administration thereof to the City of Philadelphia, instructing that it be given "to ingenious men and women who make useful inventions," and that the medal be inscribed "to the most deserving." It is quite unknown why he chose the City of Philadelphia to administer the award. On this occasion the presentation will be made by Ernest T. Trigg, Vice-President of the Board of Directors of City Trusts of Philadelphia. There will also be speeches by G. H. Dieke and W. F. G. Swann.

The **price of the banquet** will be $4.00. The local Committee will be aided if members who expect to attend will fill out and mail the form on the inside back-cover page of this Bulletin. Tickets will be sold at the registration desk, up to a deadline-hour to be determined by the hotel. Tickets which have been reserved but not called for nor paid for by 3:00 P.M. of Friday will be set free for sale to the first comers.

Post-deadline, ten-minute papers, pertaining to very recent achievements of exceptional importance, will be considered for admission to a special supplementary programme if the abstracts are received at the office of the society (the address below) not later than Friday, March 11. Papers which missed the deadline by just a couple of days are not eligible for this privilege! The names of such papers as may be accepted will be written on a blackboard near the registration desk, and the papers will be presented under the usual ten-minute rule at the end of Session M. The abstracts will not be published.

The **Council of the American Physical Society** will meet at 5:00 P. M. on Thursday in Suite 1338–1340 of the Lord Baltimore Hotel, unless contrary notice is distributed to its members.

For **prospective meetings** of the Society and the corresponding deadlines, see page 5 of this Bulletin. Here are printed also the rules for the preparation of abstracts. Please abide by them, including the rules against carbon copies, thin sheets of paper, abstracts spread over two pages, and abstracts broken into paragraphs. Violation of these rules causes much trouble and some expense to the editors.

Titles and abstracts of the papers contributed to the 1955 March meeting are printed hereinafter, and in identical form they will reappear in an early issue of *The Physical Review*. Errata will be printed on an adjacent page of *The Physical Review* if received not later than Friday, April first, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. Do not send in the abstract marked with corrections: write out the corrections in the form "Instead of . . . read. . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

Preliminary Announcement of the 1955 Spring Meeting

The 1955 Spring Meeting of the American Physical Society will be held in Washington, D. C., on Thursday, Friday, and Saturday, April 28, 29, and 30, 1955. The official hotel will be the Sheraton Park (formerly the Wardman Park). Members should make their reservations at once by letter directed to the hotel, with mention that the writer is a member of our Society. Deadline, as previously announced, will be Friday, February 18.

(Please keep this page on file!)

MEETINGS AND DEADLINES FOR THE REMAINDER OF THE SEASON 1954–1955

Place	*Meeting dates*	*Deadline date*
Baltimore	March 17–19, 1955	past
Washington	April 28–30	past
Toronto	June 22–24	April 15
Mexico City	August 29–31	June 17

Abstracts of contributed papers for the foregoing meetings are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. To avoid danger of confusion, please do not send abstracts for any meeting until the deadline date of the previous meeting is past.

RULES PRESCRIBED FOR ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

EPITOME OF THE 1955 BALTIMORE MEETING

(Personal names are those of invited speakers, except at the ends of lines where they are those of halls. DSSP stands for Division of Solid-State Physics, DHPP for Division of High-Polymer Physics.)

Thursday Morning

A. Swartz, Owen, Hanna, Bearden. Founders.
B. Irradiation effects, I; Eatherly. Caswell.
C. DHPP Symposium on biophysics of nucleic acid; Sinsheimer, Doty, Watson. Phoenix.
D. Semiconductors, I. Calvert.

Thursday Afternoon

E. DHPP Symposium, *continued:* Sutherland, Benzer, Gamow; Business Meeting of DHPP.
F. Semiconductors, II. Calvert.
G. Nuclear physics. Founders.
GA. Cyrogenics; fluid dynamics. Federal Hill.
H. Irradiation effects, II. Caswell.

Friday Morning

J. DSSP Symposium on spin-orbit effects in solids: Yafet, Karplus, Kittel, Beer; Business Meeting of DSSP. Calvert.
K. Mostly nonmetallic crystals. Caswell.
L. Luminescence. Founders.
M. Cosmic rays; post-deadline papers, if any. Federal Hill.
MA. DHP invited papers: Wall, Alexander, Taylor; high-polymer physics. Phoenix.

Friday Afternoon

N. DHPP invited papers: Flom, Schiefer, Odell; high-polymer physics. Phoenix.
P. DSSP Symposium on properties of silver halides: Mitchell, Luckey, Brown, Sack, Reif. Calvert.
Q. Photoconductivity; color centers; optical and general physics. Founders.
R. Metals, I. Caswell.

Friday Evening

Banquet of the American Physical Society. Calvert Room. Presentation of John Scott Medal to W. H. Brattain and John Bardeen. Dieke, Swann.

Saturday Morning

S. Metals, II. Caswell.
T. Photographic physics; Silver halides. Founders.
U. Buckley lecture (Apker); Donnay, Van Vleck, Dieke. Calvert.
V. High-polymer physics. Phoenix.

Saturday Afternoon

(at Johns Hopkins University)

W. Lax; cyclotron and electron-spin resonance. Shriver.
X. Koehler, Shull; ferromagnetism and ferroelectricity. Rowland.
Y. Carbons. Remsen 1.
Z. Semiconductors, III. Remsen 101.

PROGRAMME

THURSDAY MORNING AT 10:00

Founders' Room

(G. H. DIEKE presiding)

Invited Papers in Nuclear and Atomic Physics

A1. Methods of Fast Neutron Spectroscopy. C. D. SWARTZ, *Johns Hopkins University.* (30 min.)
A2. Neutron Physics at Johns Hopkins University. G. E. OWEN, *John Hopkins University.* (30 min.)
A3. Energy Levels of Beryllium 8. S. S. HANNA, *Johns Hopkins University.* (30 min.)
A4. Latest Developments in Atomic Constants. J. A. BEARDEN, *Johns Hopkins University.* (30 min.)

THURSDAY MORNING AT 10:30

Caswell Room

(T. H. BERLIN presiding)

Irradiation Effects, I

B1. On the Theory of Radiation Damage. W. A. HARRISON AND FREDERICK SEITZ, *University of Illinois.*—Two advances in theory make it possible to compare theory and experiment anew. Snyder and Neufeld[1] and the authors have found that $\bar{\nu}$, the average number of progeny per primary displaced atom is near 6 instead of 3, if one employs the simple "square-well" model with E_d near 25 ev. In addition Blatt[2] found that the resistivity for one percent of Frenkel pairs should be 2.7$\mu\Omega$ cm in copper if one extends Jongenburger's calculations for vacancies. The simple theory leads to a calculated increase in resistivity of 1.16$\mu\Omega$ cm when 3 mil copper foils are bombarded with 10^{17} 12-Mev deuterons per cm^2. The value observed by Cooper, Koehler, and Marx at 10°K is 0.23 $\mu\Omega$ cm, or is 5.0 times smaller. The discrepancy is 7.3 near liquid nitrogen temperature. Moreover the discrepancy is 5.7 for 0.5 mil specimens of copper bombarded with 0.81 Mev electrons at liquid nitrogen temperature ($\bar{\nu}=1$). The uniformity suggests either that the models employed by Jongenburger and Blatt yield values about five times too large, or that the probability of an atom being permanently displaced in copper is not unity when its kinetic energy attains the threshold. The disagreement is much less in bombarded *n*-type germanium if one assumes each displacement contributes one acceptor.

[1] W. S. Snyder and J. Neufeld, Phys. Rev. **94**, 760 (A) (1954).
[2] F. J. Blatt, Bull. Am. Phys. Soc. **29**, No. 7, 30 (1954).

B2. Source of Disordering of Alloys during Irradiation. F. SEITZ, *University of Illinois.*—Siegel[1] first found ordered alloys can be disordered efficiently under conditions in which atoms are displaced, the number of disordered atoms being much larger than the number displaced. More quantitative measurements[2] using cyclotrons show that about 120 atoms are displaced in Cu_3Au per primary displacement. Other experiments support the same efficiency factor when nucleons are employed.[3] A search has been made to disclose the mechanism for disordering. It seems unlikely that the temperatures acheived in displacement spikes are adequate to explain the disordering. Unfortunately application of the theory of temperature spikes involves evaluation of the ratio $\eta\nu_0 r_s^3/D$. Here D is the diffusion coefficient for lattice vibrational energy, ν_0 is the frequency coefficient in the basic rate process, r_s is the atomic radius and η is the number of independent rate processes per atom contributing to disorder. This ratio is assumed to be unity or less. Electron spikes seem inadequate to explain the effect since the high efficiency is observed in neutron irradiation where little electron excitation occurs. It is proposed that irreversible plastic strain which originates in thermal stresses about displacement spikes is the source of disorder.

[1] S. Siegel, Phys. Rev. **75**, 1823 (1949).
[2] Brinkman, Dixon, and Meechan, Acta Met. **2**, 38 (1954).
[3] R. R. Eggleston and F. E. Bowman, J. Appl. Phys. **24**, 229 (1953); L. R. Aronin, *ibid.*, **25**, 344 (1954).

B3. Energy Dependence of Radiation Effects in Solids.* E. PEARLSTEIN, H. INGHAM, AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—The calculations of Seitz[1] indicate a $1/E$ dependence of radiation effects on energy for charged particles passing through a thin specimen. Other calculations (see following abstract) indicate that at high energies secondary effects from nuclear reactions can be effective. In this experiment, tungsten wires previously annealed were bombarded in the Carnegie Institute of Technology sychrocyclotron with protons of several energies, and their electrical resistance was measured at room temperature before and after bombardment. Bombardments were made at 130, 260, and 410 Mev, and for each energy the resistance was found to increase by an amount proportional to the amount of bombardment. In particular for a bombardment of 10^{16} protons/cm^2 the change is 0.49 percent at 130 Mev, at 260 Mev it is 0.33 percent, and at 410 Mev it is 0.71 percent. Temperature-coefficient measurements indicate that at least most of the changes occur in the temperature independent part of the resistance. It is believed that annealing during bombardment does not affect the trend of these results. Also, this trend is well outside the probable error of measurements.

* Work supported by a U. S. Atomic Energy Commission contract.
[1] F. Seitz, Discussions Faraday Soc., No. 5 (1949).

B4. Radiation Effects in Solids Produced by Nuclear Disintegrations.* R. SMOLUCHOWSKI, E. PEARLSTEIN, AND H. INGHAM.—*Carnegie Institute of Technology.*—It has been suggested[1] that nuclear disintegrations may play an important role in the interpretation of radiation effects produced in solids by protons of energy in the 100–400-Mev range. While the cross section for this primary process of "star" formation is essentially independent of energy of the incident particle, the number and energy distribution of the prongs i.e. of the emerging nucleons is energy dependent. This is in contrast to the

other competing primary processes of electronic excitation and elastic collision which depend strongly upon the energy of the impinging particle. A detailed calculation of the spectrum of the nucleons emerging in disintegrations caused by protons of various energies in the range of interest has been made using the evaporation theory of the compound nucleus. Also the dependence of the total number of atoms displaced by these nucleons upon the energy of the primary proton has been calculated. It appears that good agreement with experiment (see preceding abstract) is obtained if one makes the plausible assumption that the most effective prongs of the stars are those due to high energy charged particles.

* Work supported by a U. S. Atomic Energy Commission contract.
[1] R. Smoluchowski, Phys. Rev. 94, 1409 (1954).

B5. Shear Modulus Recovery of Electron Irradiated Copper.* H. DIECKAMP, *North American Aviation, Inc.* (introduced by D. B. Brown).—The recovery of changes in the shear modulus of copper has been measured after bombardment by energetic electrons. Three polycrystalline wires of 99.999 percent copper were irradiated with 1 Mev electrons at liquid-nitrogen temperature to an integrated exposure of approximately 4.5×10^{18} particles/cm^2. The shear modulus was measured at liquid-nitrogen temperature after annealing in the range of −196°C to 350°C. Annealing temperatures were spaced at 25°C intervals throughout the range and the time at each temperature was 15 min. The possibility of changes due to cold work prevented the measurement of a pre-irradiation value; hence the magnitude and sign of the irradiation-induced changes are known only so far as they can be inferred from the recovery curve. The recovery can be described in terms of the following regions: −196°C to −50°C, 4 percent increase; −25°C to 50°C, no change; 75°C, ½ percent decrease; 100°C to 200°C, no change; 250°C to 350°C, 2 percent decrease. The recovery is apparently still incomplete at 300°C, but the observed changes in this region are confused by the possibilities of oxidation and recrystallization. These measurements should reflect the effects of the simplest damage, namely interstitials and vacancies, since the electrons are not sufficiently energetic to produce more complicated primary defects.

* This work supported by the U. S. Atomic Energy Commission.

B6. Effect of Quenching and Neutron Irradiation on Atomic Mobility in a Cu−Al Alloy.* CHI YAO LI† AND A. S. NOWICK, *Yale University.*—A solid solution of 17 atomic percent Al in Cu shows an internal friction peak because of stress-induced ordering, for which the relaxation strength is 0.015. Equilibrium measurements of relaxation time as a function of temperature give an activation energy of 41.6 kcal/mole. The same alloy quenched from elevated temperatures shows abnormally low relaxation times (observed in the temperature range 114°–162°C), apparently because of excess vacancies trapped by quenching. The relaxation time at a given temperature is observed to approach its equilibrium value in two distinct stages, similar to the results previously obtained for Ag-Zn alloys.[1] On the other hand, wire specimens of the Cu-Al alloy, neutron irradiated in the Brookhaven reactor at 78°K and at 323°K, show no detectable deviation of the relaxation times from equilibrium values. The quenching experiments indicate that vacancies are mobile only at temperatures above 100°C. Vacancies produced by irradiation must therefore be destroyed by interstitials or other defects which are mobile below room temperature.

* Work supported by the U. S. Army Office of Ordnance Research.
† Now at Lehigh University, Bethlehem, Pennsylvania.
[1] A. E. Roswell and A. S. Nowick, J. Metals 5, 1259 (1953).

B7. Conductivity of Teflon and Polyethylene During Gamma Irradiation. R. A. MEYER AND F. L. BOQUET, *U. S. Naval Radiological Defense Laboratory.*—An investigation has been undertaken to measure the change in conductivity of insulating materials undergoing irradiation by gamma-rays as a function of temperature and dose rate. The material measured was polyethylene and teflon (polytetrafluorine). The irradiation sources employed in this study were Co^{60} gamma-rays and x-rays from a gold target bombarded by electrons from a Van de Graaff generator. The flux intensities from the two cobalt sources were approximately 0.6 r per min and 423 r per min, and those from the incident electrons, 30 r per min to 1250 r per min. Samples, 0.16 cm thick and 4.1 cm in diameter, were mounted on one end of an aluminum cylinder in a vacuum. The current passing through the insulator was measured with two types of electrometers. All measurements were made with a voltage across the sample. The voltage was varied from −600 to +600 volts. The temperature range investigated was from room temperature to −170°C. In general, the conductivity of teflon was greater than that of polyethylene under gamma irradiation. Evidence obtained from variation of the decay as a function of temperature indicates trapping effects are present.

B8. Detection of the Vacancies Created in NaCl by X-Rays. H. W. ETZEL, *U. S. Naval Research Laboratory.*—The production of vacancies by x-rays in sodium chloride has been observed using optical techniques. The absorption of the ultraviolet induced *F*-band is measured in single crystals of sodium chloride; then the band is optically bleached. The crystals are then x-rayed and optically bleached. The crystals are again subjected to the same ultraviolet radiation as they received prior to x-raying, and the optical absorption of the *F*-band measured. The *F*-band observed after x-raying is enhanced 10-fold over that observed prior to x-raying. This result is interpreted to indicate the production of vacancies by x-rays.

Invited Paper

B9. The Effect of Radiation Damage on the Electrical and Thermal Properties of Graphite. W. P. EATHERLY, *North American Aviation.* (30 min.)

THURSDAY MORNING AT 10:00

Phoenix Room

(J. D. WATSON presiding)

DHPP Symposium on Biophysics of Nucleic Acid

C1. The Chemistry of Nucleic Acids. R. L. SINSHEIMER, *Iowa State College.* (30 min.)

C2. The Size and Shape of the Nucleic Acids as Revealed by Physical-Chemical Techniques. PAUL DOTY, *Harvard University.* (30 min.)

C3. Nucleic Acid Structure as Revealed by X-Ray Diffraction. J. D. WATSON, *California Institute of Technology.* (30 min.)

THURSDAY MORNING AT 9:30

Calvert Room

(D. T. STEVENSON presiding)

Semiconductors, I

D1. A Semiconducting Diamond.* W. J. LEIVO AND R. SMOLUCHOVSKI, *Carnegie Institute of Technology.*—The class IIb diamonds exhibit rather rare optical and electrical properties.[1] In order to investigate what type of imperfections may be responsible for these properties, the dark resistivity was measured between room temperature and 425°C. It appears that these diamonds behave like typical impurity activated semiconductors with a low concentration of impurities and produce a good rectification with a metal point. At low temperatures, their resistance decreases with increasing temperature while at high temperatures it increases with increasing temperature. The minimum is reached at about 360°C. Below this minimum the resistivity decreases with increasing current while at higher temperatures the dependence is reversed indicating that this effect is due primarily to heating. This is presumably the reason for the resistance hysteresis observed by Custers. The slope of the dependence of $k \ln R$ on $1/T$ at low temperatures is about 0.35 ev. The crystal is photoconductive in the visible and shows inhomogeneities in its electrical properties.

* Work supported by a U. S. Atomic Energy Commission contract.
[1] J. F. H. Custers, Physica **18**, 489 (1952); **20**, 183 (1954). We are indebted to Dr. Custers for supplying the diamond.

D2. Optical Absorption Spectra of Thorium Oxide.* J. H. BODINE AND F. B. THIESS, *Bartol Research Foundation.*—Absorption measurements in the region of 2200 A to 10 000 A were made on optically polished thoria crystals of 99.9 percent purity. Firing the crystals in air and in vacuum at different temperatures gave the red, white, and yellow forms described by Weinrich and Danforth.† The present improved instrumentation gave a cutoff at 3550 A for all forms. Vacuum firing at high temperature (1500°) gives a yellowish form. The white form is produced by lower temperatures and/or short times. Results will be reported regarding the progressive change from white to yellow forms as the temperature and time of firing are increased. Thin films prepared by oxidizing films of metallic thorium show rapid increase of absorption at 3550 A. Since the white state of thoria shows no absorption band, it seems to be the stoichiometric form of thorium oxide, with an optical intrinsic gap at 3.5 ev. The change to the red form seems attributable to thorium vacancies, since the oxygen ion is apparently too large to enter into interstitial sites. The absorption band at 4050 A (3.0 ev) in the yellow crystals is presumably due to oxygen vacancies or to interstitial thorium.

* Assisted by the Office of Ordnance Research.
† *Advances in Electronics*, (1953), Vol. V, p. 203.

D3. Effect of Impurities on Mobility in *n*-Type InSb.* T. C. HARMAN, R. K. WILLARDSON, AND A. C. BEER, *Battelle Memorial Institute.*—The electron mobility in *n*-type InSb has been determined from Hall and resistivity data at room temperature and at 80°K in specimens having extrinsic carrier concentrations ranging from 10^{14} to 10^{17} cm^{-3}. Samples were cut from different locations along the zone-refined ingots in order to study the effects of varying amounts of compensation. In the purest specimen, mobility values of 74 000 cm^2/volt-sec at 300°K and 500 000 cm^2/volt-sec at 80°K were measured. Deviations from lattice mobility due to impurity scattering became apparent only at temperatures below 125°K. With an effective mass of 0.036 m_0, it was found that the Conwell-Weisskopf equation could effectively account for the observed mobility values as long as the impurity concentrations were below 10^{15} cm^{-3}. At impurity concentrations of 10^{17} cm^{-3}, however, both the Conwell-Weisokopf and Brooks-Herring relationships gave results about an order of magnitude below the observed mobility values.

* Supported by Wright Air Development Center contract.

D4. Magnetic Susceptibility of Indium Antimonide. J. H. CRAWFORD, JR., AND D. K. STEVENS, *Oak Ridge National Laboratory.*—The magnetic susceptibility of single crystal specimens[1] of InSb have been measured as a function of temperature over the range from 90° to 600°K. The purity of the specimens (~10^{16} carriers/cm^3) was such that the specimens were intrinsic above 200°K. The diamagnetic susceptibility increased markedly with temperature with the onset of intrinsic behavior. The contribution due to intrinsic carriers has been estimated by subtracting the low temperature value of the susceptibility which in *p*-type material is expected to be approximately the contribution of the lattice. A plot of the logarithm of the carrier susceptibility divided by $T^{\frac{3}{2}}$ *vs* reciprocal temperature yields a straight line in the intrinsic range with a slope corresponding to an energy gap of 0.19 ev. This value is in reasonable agreement with the thermal energy gap obtained by other methods.[2] A tentative analysis of the results indicates an electron effective mass of $m^* \simeq 0.025\ m_0$, a value somewhat smaller than obtained from electrical measurements.

[1] We are indebted to Dr. M. Tannenbaum of Bell Telephone Laboratories who furnished the specimens.
[2] Breckenridge, Blunt, Hosler, Frederikse, Becker, and Oshinsky, Phys. Rev. **96**, 571 (1954).

D5. Galvano Magnetic Effects in InSb. W. R. HOSLER AND H. P. R. FREDERIKSE, *National Bureau of Standards.*—The magnetoresistance and magneto-Hall effects of InSb have been measured as a function of crystal orientation, magnetic field strength and temperature. Both *p*- and *n*-type crystals have been studied; the carrier concentrations at liquid nitrogen temperature were 3×10^{16}/cc(*p*) and 10^{15}/cc(*n*), respectively. Measurements were made at 300°K and at 78°K on samples cut in the (100) as well as the (110) direction. Magnetic fields (both parallel and perpendicular to I) ranged from 100 to 5000 oersted. The galvanomagnetic effects in these InSb samples are complicated by several factors: mixed conduction at room temperature, two different scattering mechanisms for the charge carriers at 78°K, and high electron mobility. Both the weak field ($H<1000$ oersted) and the strong field cases ($H=$several thousands of oersteds) can be studied on *n*-type samples. Results indicate that the effects in *p*-type InSb are in agreement with the simplified theory[1] which assumes spherical energy surfaces. The data on *n*-type samples suggest, however, a more complicated structure of the conduction band.

[1] F. Seitz, Phys. Rev. **79**, 372 (1950).

D6. Hall Effect and Resistivity of Indium Antimonide at Low Temperatures.* H. FRITZSCHE AND K. LARK-HOROVITZ, *Purdue University.*—The Hall coefficient R and the resistivity ρ of *p*-type indium antimonide have been measured between 1.3°K and 300°K. The specimens were single crystals containing 10^{15} to 3×10^{16} acceptors per cc. All specimens showed

the same anomalous behavior of the Hall coefficient R—maximum at low temperatures—and the resistivity between 12°K and 20°K as was first observed on germanium in 1950.[1] The Hall maximum decreases and shifts to higher temperatures as the impurity content is increased. In the lowest temperature range ρ depends strongly on impurity content suggesting conduction in an impurity band. The magnetoresistive ratio of the purer samples changes from positive to negative values at about 11°K as the temperature is lowered.

* Work supported by U. S. Signal Corps.
[1] C. S. Hung and J. R. Gliessman, Phys. Rev. **79**, 726 (1950). See also J. Hatton and B. V. Rollin, Proc. Phys. Soc. (London) **A67**, 385 (1954).

D7. Properties of Mg_2Sn. R. F. Blunt, H. P. R. Frederikse, and W. R. Hosler, *National Bureau of Standards.*—This compound has been shown to have the fluorite structure and to be a semiconductor with a small energy gap.[1,2] Both n- and p-type samples have been prepared. Results of Hall and resistivity measurements at temperatures between 78°K and 300°K will be presented. The electron mobility is about 3300 cm²/volt-sec at liquid nitrogen temperature and follows a T^{-3}-dependency in the range 100–300°K. The energy gap appears to be 0.32 ev at absolute zero. From the mobility ratio (1.2) one calculates effective masses of the order of m for both holes and electrons. Optical absorption measurements have been made on several cleaved samples at 300°K and at lower temperatures. The location of the absorption edge is in agreement with electrical data; the temperature shift is -4×10^{-4}ev/deg. Observations on the photoresponse of this material will also be presented.

[1] G. Busch and U. Winkler, Helv. Phys. Acta **26**, 395 and 578 (1953).
[2] W. D. Robertson and H. H. Uhlig, Trans. Am. Inst. Mining Met. Engrs. **180**, 245 (1949).

D8. Mobility of Holes in Si and Ge. H. Ehrenreich and A. W. Overhauser, *Cornell University.*—The mobility of holes due to lattice scattering has been calculated taking into account transitions within and between the two degenerate valence bands at $\mathbf{k}=0$. The slight deviations of the energy surfaces from spherical symmetry were neglected, and matrix elements were calculated from Bloch functions whose cellular dependence was assumed to be of pure p character. Only one unknown constant C, equal to the kinetic energy at $\mathbf{k}=0$, enters the theory. Using effective mass data from cyclotron resonance experiments, and assuming reasonable values for C, the theoretical mobilities at room temperature are an order of magnitude larger than experimental values. The usual $T^{-1.5}$ temperature dependence was obtained. Transverse and longitudinal phonons were found to be about equally effective in scattering. Umklappprozesse do not occur, scattering from optical modes is completely negligible, and the temperature dependence of effective mass values due to self energy interaction with the phonon field is too small to explain the anomalous temperature dependence of the mobility. One can prove that second- and higher-order scattering effects (many phonon processes) need not be considered, or more precisely, the effect of such processes on transport theory is automatically included in a first-order perturbation calculation.

D9. Theory of the Photomagnetoelectric Effect in Semiconductors. W. van Roosbroeck, *Bell Telephone Laboratories.*—An ambipolar treatment[1] furnishes general differential equations for added carrier transport with magnetic field. These equations are applied to the photomagnetoelectric effect in an infinite slab with radiation incident on one surface and steady parallel magnetic field. The condition that the curl of the electrostatic field must vanish requires a constant (depth-independent) photomagnetoelectric field along the slab and a nonvanishing curl of local total current density $\mathbf{I}$. It follows that photomagnetoelectric open-curcuit voltage V_0 is the same on both surfaces, with $\mathbf{I}$ a circulating current. Derivations[2] that assume zero $\mathbf{I}$ and predict differing voltages on the surfaces are accordingly incorrect. Correct V_0 has been given, as calculated for a slab with end electrodes for which constant photomagnetoelectric field was assumed.[3] Photomagnetoelectric short-circuit current as well as V_0 is derived for the small-signal case and for large light intensity, assuming constant surface recombination velocities and lifetime. The nonlinear case of arbitrary light intensity can be solved exactly without recourse to numerical integration of the differential equations.

[1] W. van Roosbroeck, Phys. Rev. **91**, 282 (1953).
[2] Moss, Pincherle, and Woodward, Proc. Phys. Soc. (London) **B66**, 743 (1953).
[3] P. Aigrain and H. Bulliard, Compt. rend. **236**, 595 (1953); H. Bulliard, Ann. phys. **9**, 52 (1954).

D10. The Faraday Effect in Semiconductors at Microwave Frequencies.* Richard Rau and P. H. Miller, Jr., *University of Pennsylvania*—The free charge carriers cause a rotation of the plane of polarization when a plane polarized electromagnetic wave passes through a nonferromagnetic semiconductor and a static magnetic field is applied along the direction of propagation. The Drude-Zener theory predicts the following difference between the squares of the propagation constants for left and right circularly polarized radiation respectively, which then determines the angle of rotation.

$$k_+^2-k_-^2=\frac{2\mu_0[\sigma_0\omega\mu B[1+(\mu B)^2+(\omega\tau)^2]+2i(\mu B)(\omega\tau)\sigma_0\omega(1+i\omega\tau)]}{[1+(\mu B-\omega\tau)^2][1+(\mu B+\omega\tau)^2]},$$

where B is the magnetic field, σ_0 the dc conductivity, $\omega/2\pi$ the frequency, μ the mobility, and τ the relaxation time. Room temperature measurements of this angle of rotation on various samples of germanium, gave values of 4000 ± 100 cm²/volt sec and 3400 ± 100 cm²/volt sec for the electron and hole mobilities respectively. The method should be applicable to powdered samples after the internal field has been determined by a Clausius-Mosotti type approximation.

* This work supported by the U. S. Air Force.

D11. Configuration Interaction and Holes. P. J. Price, *IBM Watson Laboratory.*—Hole excitations are known to exist in valence crystals where the electron wave function $\Psi(\mathbf{r}_1,\cdots\mathbf{r}_N)$ of the ground state is not a determinant. The conventional description of the state with a hole thus needs to be generalized: We propose a wave function $N^{\frac{1}{2}}\int\phi^*(\mathbf{r}_1)\Psi d^3\mathbf{r}_1$, and determine $\phi(\mathbf{r})$ by requiring the energy expectation to be stationary. By the transformation $|\phi'\rangle=R^{\frac{1}{2}}|\phi\rangle$, where R is the one-particle density matrix for Ψ, we obtain a "wave equation" (with the excitation energy as eigenvalue) for ϕ' (the solutions being bands of functions of Bloch form). There are in general more than N formal solutions. It will be argued that, in certain conditions which will be discussed, there should in consequence actually be more of these bands of hole states than the determinant approximation, for the "valence shell," would require.

D12. On Smakula's Equation in Insulating Solids. D. L. Dexter, *University of Rochester.*—Smakula's equation relates the product of the oscillator strength f and the concentration n of an absorbing impurity to the peak value and energy width of the absorption spectrum. This equation is based on two assumptions whose validity will be examined. The first that the band shape is classical, will be shown to lead to an overestimate of nf by the factor $(\pi\ln2)^{\frac{1}{2}}=1.48$ in simple cases where the shape is expected to be approximately Gaussian. The second assumption essentially was that the electric field inducing the transition at the impurity was the Lorentz "effective field." Conditions of validity for this and alternative assumptions will be discussed. In diffuse centers, such as impurity atoms in Ge, the product nf is underestimated in using Smakula's equation by the factor $9/(\kappa+2)^2$, or by a factor of $\sim1/40$. Only in the case of tightly bound centers whose

absorption is far from resonance with the host crystal may Smakula's assumption be valid. Some of the influences of resonance phenomena will be discussed for such real cases as the *F*-center or KCl:Tl.

D13. Saturation Hall Constant and Magnetoresistance in Semiconductors. JOHN A. SWANSON, *International Business Machines Corporation.*—The limit of the Hall constant as the magnetic field becomes infinitely large has been investigated using two different approaches: (a) the crystal momentum "force equation" approximation, and (b) perturbation theory, taking as unperturbed wave functions those which exist in the magnetic field alone. It is found by the first method that the saturation constant is 1/nec for all orientations provided that all relevant electrons in each unfilled band are confined to finite disjoint regions in extended (infinite) crystal momentum space. The unscattered orbits in *P*-space, which determine the saturation constant, are then reentrant for sufficiently large ratios of magnetic field to longitudinal current. The same saturation constant is found by the second approach, provided that in a magnetic field all relevant electrons may occupy states for which a small electric field constitutes only a perturbation. Similar results apply to holes. Saturation magnetoresistance will also be discussed briefly.

D14. Some Magneto-Electric Effects in Germanium in Strong Magnetic Fields. WARREN E. HENRY, *U. S. Naval Research Laboratory.*—Demonstration of change from quadratic to linear dependence of the electrical resistance of germanium on transverse magnetic fields has been carried out by Kapitza,[1] and approximate theoretical linearization of the field dependence at high fields has been achieved by Harding,[2] giving qualitative agreement with this and later work by Pearson and Suhl,[1] except that the linear range begins at lower fields in the theoretical relation. Kapitza worked under the handicap of impure germanium and pulsed fields of 0.01 sec duration. He predicted a linear region at lower fields with pure germanium. The present investigation has been carried out with the specimen purity improved over 100 fold (kindly supplied by Sylvania) and in steady magnetic fields to more than 100 000 gauss. Thus, for comparable fields, at 300°K and 77.4°K, our results show a fourfold reduction in the field for onset of linearity and a tenfold advantage in $\Delta R/R$. Both the magnetoresistance and Hall effect can be used for high precision magnetometry. A nonmonotonic field dependence of the resistance was observed at 4.2°K.

[1] P. Kapitza, Proc. Roy. Soc. (London) **A123**, 292 (1929); G. L. Pearson and H. Suhl, Phys. Rev. **83**, 768 (1951).
[2] J. W. Harding, Proc. Roy. Soc. (London) **A140**, 205 (1933).

D15. Theory of the Anisotropy of Magnetoresistance for Single Crystals.* L. P. KAO AND E. KATZ, *University of Michigan.*—Progress in the theory of the magnetoresistance of an anisotropic single crystal, belonging to any of the 32 point groups, for arbitrary orientation of the sample and arbitrary orientation of the applied magnetic field is presented. This theory is a continuation of what we have previously reported.† It is shown that the magnetoresistance is an even power series of the magnetic field strength. The coefficients of this series are given in terms of the direction cosines of the magnetic field and of the measured current with respect to the crystal axes and in terms of components of tensors of rank $2n+2$, where n is the highest power of the magnetic field required to interpret an experiment. A method has been developed to determine all symmetry relations of the tensor components for each of the 32 point groups. Tensor components tabulated accordingly are given for all 32 point groups for n up to 4, although the method is valid for any value of n.

* Sponsored by U. S. Signal Corps Supply Agency.
† L. P. Kao and E. Katz, Phys. Rev. **94**, 1453(A) (1954).

THURSDAY AFTERNOON AT 2:00

Phoenix Room

(J. D. WATSON presiding)

Continuation of the DHPP Symposium on Nucleic Acid

E1. Infrared Analysis of the Structure of Proteins and Nucleic Acids. G. B. B. M. SUTHERLAND, *University of Michigan.* (30 min.)

E2. Genetic Fine Structure and Its Relation to the Deoxyribonucleic Acid Molecule. SEYMOUR BENZER, *Purdue University.* (30 min.)

E3. The Transfer of Information from Nucleic Acids to Proteins. G. GAMOW, *George Washington University.* (30 min.)

Business Meeting of the Division of High-Polymer Physics

THURSDAY AFTERNOON AT 2:00

Calvert Room

(H. Y. FAN presiding)

Semiconductors, II

F1. Some Properties of Germanium Doped with Manganese. H. H. WOODBURY AND W. W. TYLER, *General Electric Research Laboratory.*—Manganese introduces deep levels in germanium similar to those observed in iron-,[1] colbalt-,[2] and nickel-doped[3] germanium. These levels are at 0.35 ± 0.02 ev from the conduction band (n-type) and 0.16 ± 0.01 ev from the

valence band (p-type) and have been identified from the temperature dependence of resistivity. Three different sources of electrolytic manganese have been used. The distribution coefficient for Mn in Ge is about 10^{-4}. At temperatures below 200°K, high resistivity n-type samples show high photosensitivity and slow photoconductive decay which is not surface dependent. Evidence for hole trapping in both n- and p-type material has been observed by studying Hall mobility of optically induced carriers. Although exponential photoconductivity decay curves have been observed, the recovery process does not appear to be a simple evaporation process. Injection breakdown effects similar to those reported for iron-doped samples[2] have also been observed in n-type Mn-doped crystals.

[1] W. W. Tyler and H. H. Woodbury, Phys. Rev. **96**, 874 (1954).
[2] Tyler, Newman, and Woodbury, Phys. Rev. **97**, 669 (1955).
[3] W. W. Tyler, Phys. Rev. **96**, 226 (1954).

F2. Gold, an "Amphoteric" Impurity Element in Germanium. W. C. DUNLAP, JR., *General Electric Research Laboratory.**—Gold is shown to be an "amphoteric" element in germanium; that is, it can either donate or accept electrons depending upon the type and amount of other impurities present. Previously,[1] the acceptor action of gold in germanium had been described, and it was shown that there were two states 0.15 and 0.55 ev above the valence band. Morton, Hahn, and Schulz have found evidence for a third state which they interpret as the first acceptor level. In the present investigation, the existence of a third state is confirmed and it is shown, to a high degree of certainty, that this is a donor state 0.05 ev above the valence band. When gold is added to germanium containing fifth column acceptors in amounts less than the gold content, the carrier density at 77°K remains constant, and the carriers acquire an activation energy of about 0.05 ev. Good agreement was obtained with several sources of gold. It is suggested that neutral gold atoms give up electrons to low-lying empty states and become Au^+. The upper states remain Au^- and Au^{--}. The donor level appears to be analogous to the donor level in silicon.

* Present address, General Electric Company, Syracuse, New York.
[1] W. C. Dunlap, Jr., Phys. Rev. **91**, 1282 (1953).

F3. Optical Effects in Plastically Deformed Germanium. H. G. LIPSON, E. BURSTEIN, AND P. L. SMITH, *U. S. Naval Research Laboratory.*—N-type germanium specimens of 1 ohm-cm resistivity were plastically deformed from 3 to 15 percent at about 700°C. The more strongly deformed specimens were found to be converted to p-type. All of the deformed specimens exhibited a shift in the intrinsic absorption edge as well as an extended tail. Those samples which were converted to p-type also exhibit the characteristic absorption bands due to free holes. The long wavelength tail may possibly be associated with optical transitions of holes from dislocation acceptor levels[1] to the valence band. These results differ from those obtained for neutron bombarded germanium[2] which exhibits no shift of the absorption band and a tail of somewhat different character from that found in the plastically deformed material.

[1] Pearson, Read, and Morin, Phys. Rev. **93**, 666 (1954).
[2] Unpublished data from work at NRL in collaboration with J. H. Crawford and J. W. Cleland of Oak Ridge National Laboratory.

F4. Electrical Properties of Electron Bombarded Ge.* E. E. KLONTZ, R. R. PEPPER, AND K. LARK-HOROVITZ, *Purdue University.*—To observe properties of defects introduced by 4.5-Mev electron bombardment of Ge, Hall values R and resistivity ρ for various N-type and p-type samples have been determined as a function of bombardment at different temperatures. For both N and P-type samples bombarded near nitrogen temperature (87°K), R and ρ increase initially. While still N-type, a sample illuminated with white light exhibits photoconductivity which increases very slowly in the presence of the light indicating existence of hole traps. Nonequilibrium conditions for initially p-type and for N-type samples which have been converted are indicated by a steady increase in values of R and ρ after bombardment. Bombardments near 200°K produce converted samples having a photoconductivity which decays in a matter of minutes. A 40 ohm cm. p-type sample at this temperature changes only slightly with bombardment while the resistivity of a 6 ohm cm sample increases. Production of energy levels about 0.2 ev above the valence band is indicated. Bombardments at 2°C convert n-type samples to p-type, which then revert back to n-type, at the bombardment temperature, in a matter of hours. In a 40 ohm cm p-type sample, R and ρ decrease on bombardment, whereas they increase slightly in a 5 ohm cm sample. Samples bombarded at 87°K and 200°K also revert at about 0°C unless they have been bombarded with very large flux.

* Supported by the U. S. Atomic Energy Commission and Signal Corps contract.

F5. Photoconductivity of Electron-Bombarded Ge.* F. STOECKMANN, E. KLONTZ, H. Y. FAN, AND K. LARK-HOROVITZ, *Purdue University.*—The photoconductivity of n-type Ge, illuminated with light in the fundamental absorption region, increases during bombardment with fast electrons (6 Mev) at 90°K. The increase is fast at the start of irradiation, slower after prolonged bombardment amounting to two orders of magnitude. The time constants of the rise and decay curves are about one second. The photoconductivity decreases as the sample is converted to p-type. In the p-type region the response is smaller than before bombardment. These observations show the production of hole traps by the bombardment. Direct evidence for such traps is given by the spectral distribution of the photoconductive response, which after bombardment shows two bands beyond the absorption edge at about 0.35 ev and 0.55 ev. After conversion to p-type the 0.35 ev band disappears while illumination in the 0.55 ev band *decreases* the conductivity, therefore these bands must be due to electron transitions from localized states to the conduction band. The 0.35 ev state seems to be the trap responsible for the large increase of photoconductivity. Previously reported results[1] are confirmed after the sample had been warmed to room temperature.

* Work supported by a Signal Corps Contract and U. S. Atomic Energy Commission Contract.
[1] Fan, Kaiser, Klontz, Lark-Horovitz, and Pepper, Phys. Rev. **95**, 1087 (1954).

F6. Properties of Powdered Germanium and Effects of Heat-Treatment. E. A. KMETKO, *Sylvania Electric Products Inc.*—Properties of germanium powders made from both n- and p-type materials were studied. In both cases a reaction with water occurs to form a strong unidentified acid (pH of aqueous slurries observed as low as ~2). After heat-treatment in helium ($\gtrsim$500°C) or exposure to air for several months this property is lacking. The electrical resistivity, measured for compressed powders, increases with time, but as a result of heat-treatment the change may be retarded, or apparently even halted, depending on the conditions. Treatment at the lower temperatures, or long exposure to air, results in non-ohmic conductivity ($i \sim \exp \alpha V^{\frac{1}{2}}$) which depends approximately exponentially on pressure. This and other evidence to be presented (effects of ambients, etching, etc.) show that the non-ohmic (Schottky type) character of the contact between particles of disturbed germanium is caused by the presence of thick surface layers of GeO_2. The stabilizing effect of heat-treatment can be interpreted according to Clarke's picture[1] whereby the normally formed water soluble GeO_2 (hexagonal) is converted to the insoluble form (tetragonal).

[1] E. N. Clarke, Bull Am. Phys. Soc. **30**, No. 1, 39 (1955).

F7. Infrared Absorption in *N*-Type Germanium.* W. SPITZER, R. J. COLLINS,† AND H. Y. FAN, *Purdue University.*—Absorption in n-type germanium is investigated from 5 to 30 microns at different temperatures on samples of various carrier concentrations. At room temperature the absorption coefficient, α, is roughly proportional to the carrier concentration, n, but this is a systematic change in the shape of $\alpha(\lambda)$ curve for samples with different n. At 450°K, curves of α/n for different samples agree fairly well. The quantum-mechanical formula for carrier absorption due to lattice scattering[1] gives the right order of magnitude for α/N using $m^*/m=0.135$, but the calculated curve rises nearly as λ^2 whereas the experimental curve is less steep. At 78°K, $\alpha(\lambda)$ curves for different samples have the same shape, nearly as λ^3. Theory of absorption by carriers with impurity scattering[1] gives α increasing as $\lambda^{3.5}$ and α/n proportional to the impurity concentration N. Various samples, including one with compensating impurities, give $\alpha/N=(a+bN)$. The results indicate that at high temperatures lattice scattering effect is dominant and at low temperatures impurity scattering becomes important for the absorption.

* Work supported by a Signal Corps Contract.
† Now at Bell Telephone Laboratories.
[1] H. Y. Fan and M. Becker, *Semiconducting Materials* (Butterworths, London, 1951), p. 132.

F8. Hall Effect and Resistivity of *P*-type Germanium at Low Temperatures.* K. LARK-HOROVITZ AND H. FRITZSCHE, *Purdue University.*—The Hall coefficient R and the resistivity ρ of germanium single crystals with gallium concentrations larger than 2×10^{16} atoms per cc have been measured between 1.3°K and 300°K. The temperature dependence of the conductivity can be described by a sum of three exponential terms instead of two, as in the case of purer samples. In contrast to the behavior of samples with smaller impurity content, the Hall curves of these samples do not have a sharp maximum but a very irregular shape which is different for different impurity contents. At low temperatures the Hall curves do not approach the high temperature exhausting range value as was predicted by Hung,[1] on the basis of measurements carried out with polycrystalline samples, but show a definite slope at still lower temperatures. In all cases thus far the sign of R is the same throughout the whole temperature range in which observations were made.

* Work supported by Signal Corps Contract.
[1] C. S. Hung, Phys. Rev. **79**, 727 (1950).

F9. Self-diffusion in Germanium.* WILLIAM M. PORTNOY, HARRY LETAW, JR., AND LAWRENCE SLIFKIN,† *University of Illinois.*—An accurate determination of the self-diffusion coefficient in germanium has been obtained. As reported earlier,[1] radioactive Ge^{71} was electroplated onto small slabs of germanium. After annealing at constant temperature in the range 928–766°C, the specimens were sectioned on the precision grinding machine.[2] Between these temperatures, the data may be represented by $D=7.8\exp(-68\,500/RT)$ cm²/sec. The probable errors in the frequency factor and the activation energy are ±3.4 cm²/sec and ±0.96 kcal/mole, respectively. No further cases of grain boundary diffusion attributable to grain growth during the diffusion anneal have been observed.[1]

* Supported in part by the Office of Naval Research, the Air Research and Development Command of the U. S. Air Force, and a grant from the Motorola Corporation.
† Now at the University of Minnesota.
[1] Letaw, Slifkin, and Portnoy, Phys. Rev. **93**, 892 (1954).
[2] Letaw, Slifkin, and Portnoy, Rev. Sci. Instr. **25**, 865 (1954).

F10. Optical Properties of Group III Elements in Silicon. E. BURSTEIN, G. PICUS, B. HENVIS, AND M. LAX, *U. S. Naval Research Laboratory.*—Optical measurements on B. T. I. p-type silicon doped with group III-B (boron, aluminum, gallium, and indium)[1] elements have been carried out at liquid helium temperatures. The variation in ionization energies[2] among these elements are found to be accompanied by appreciable variations in the character of the excitation and photo-ionization absorption spectra. Analysis of the data indicates that, in going from boron to indium, the energies of the p-states remain approximately unchanged with respect to the valence band, while the $1s$ states move further from the top of the valence band. This behavior is understandable in terms of a modified hydrogen model with a potential well at the impurity atom.[3] This perturbing potential, due to the impurity ion core, may be expected to affect s-states more strongly that p-states.

[1] These were kindly supplied by J. Burton, R. G. Shulman, and F. J. Morin of the Bell Telephone Laboratories.
[2] Morin, Maita, Shulman, and Hannay, Phys. Rev. **96**, 833 (1954).
[3] G. F. Koster and J. C. Slater, Phys. Rev. **96**, 1208 (1954).

F11. Birefringence in Silicon. W. C. DASH, *General Electric Research Laboratory.*—An infrared image tube or "snooperscope" using a cesium-silver-oxide photoemitting surface makes possible visual studies of birefringence in silicon. A polished slab cut parallel to the axis of an ingot grown by the Czochralski technique has a birefringent pattern characteristic of the conditions of growth. In crystals rotated during growth a series of birefringent "stripes" are found apparently parallel to the growth surface and independent of crystal orientation. These stripes can be created deliberately by suddenly varying the temperature of the melt as in the rate-growing of $p-n$ junctions.[1] Correlations have been found between these patterns and heat treatment effects upon electrical properties.[2] Crystals unrotated during growth do not show stripes, but, surprisingly, are also birefringent. Specimens with large numbers of parallel twins also show characteristic but unrelated birefringence patterns of a different type from "growth" birefringence. Birefringence in alloy contacts, in grain boundaries, bent specimens, specimens with precipitated impurities, etc., will be discussed. Birefringence has also been detected in germanium, but lack of an infrared image-forming device sensitive in the range of germanium transparency prevents detailed studies.

[1] R. N. Hall, J. Phys. Chem. **57**, 836 (1953).
[2] Fuller, Ditzenberger, Hannay, and Buehler, Phys. Rev. **96**, 833(A) (1954).

F12. Reverse Current and Carrier Lifetime as a Function of Temperature in Germanium and Silicon Junction Diodes. E. M. PELL, *General Electric Research Laboratory.*—The reverse current and carrier lifetime have been measured in a series of germanium and silicon diodes as a function of temperature between 200°C and −196°C. In germanium, the lifetime reaches a plateau at low temperatures, and its behavior can be explained in terms of the Hall-Schockley-Read[1,2] recombination theory using two recombination center levels. Silicon behaves in a roughly similar fashion. The behavior of $\log i_R$ *vs* $1/T$, the magnitude of i_R, and the shape of i_R *vs* V suggest that the reverse current is produced predominantly by charge generation within the depletion layer in germanium at low temperatures and in silicon up to room temperature and often above. The generation centers are about 0.3 ev deep in Ge and 0.5 ev deep in Si.

[1] R. N. Hall, Phys. Rev. **87**, 387 (1952).
[2] W. Shockley and W. T. Read, Jr., Phys. Rev. **87**, 835 (1952).

F13. Visible Light from a Si $p-n$ Junction. R. NEWMAN, W. C. DASH, R. N. HALL, AND W. E. BURCH, *General Electric Research Laboratory.*—We have observed that when a silicon $p-n$ junction was biased in the reverse direction beyond the point of breakdown, a yellowish white light was emitted at the junction. A number of heavily doped grown junctions (reverse breakdown of order 10–20 volts) were examined and all showed the effect to a greater or lesser degree. The efficiency of light emission is sensitive to surface treatment. When

examined under high magnification (500×), it was found that the light was emitted in regions at the junction of order of 10 microns wide and often extending several mm along the junction with uniform intensity. The spectrum of the light taken with a low dispersion monochromator and a photomultiplier detector showed a relatively constant output from about 1.8 to 2.4 ev followed by a rapid drop off out to 3.4 ev, the limit of our measurement. The origin of the light is in doubt. Light is emitted when the junction is operated in vacuum indicating that it does not result from an external gas discharge. It may result from a breakdown in the oxide film or in the silicon itself. It is energetically possible that such light could arise from recombination in an avalanche breakdown.[1]

[1] K. G. McKay, Phys. Rev. **94**, 877 (1954).

THURSDAY AFTERNOON AT 2:00

Founders' Room

(F. RASETTI presiding)

Nuclear Physics

G1. Quadrupolar Splitting of Nuclear Resonance Lines in the Alums.* W. G. SEGLEKEN AND H. C. TORREY, *Rutgers University.*—Nuclear magnetic resonances of Al^{27} in single crystals of $AlK(SO_4)\cdot 12H_2O$ and $Al(NH_4)(SO_4)_2\cdot 12H_2O$ were observed at 12 mc/sec (10.8 kilogauss). The crystals were mounted so that they were rotatable about a (001) axis kept perpendicular to the magnetic field. In each case the line was split into five equally spaced lines. The spacing was proportional to $\sin 2\theta$ where θ is the angle between the magnetic field and the (100) direction. The maximum separations between adjacent lines ($\theta=45°$) are 30.0 ± 0.6 kc/sec for the potassium salt and 33.5 ± 0.6 kc/sec for the ammonium salt. This splitting is caused by a small trigonal field along the body diagonals interacting with the nuclear quadrupole moment of Al^{27}. A similar field exists in the chromium isomorphs of these salts and produces there a Stark splitting of the ground state of the paramagnetic Cr ions. The ratio ($1.12\pm.03$) of the above quadrupolar splittings in the aluminum alums is the same as the ratio ($1.12\pm.07$) of the ground-state splittings in the corresponding chrome alums as determined[1] by paramagnetic resonance.

* Supported by the U. S. Air Force.
[1] Bagguley and Griffiths, Proc. Roy. Soc. (London) **A204**, 188 (1950).

G2. Quadrupole Moments of Rb^{85} and Rb^{87}. B. SENITZKY, I. I. RABI, AND M. L. PERL, *Columbia University.*—The atomic beam magnetic resonance method for excited atomic states[1-4] has been applied to Rb^{85} in the $5P_{\frac{1}{2}}$ hyperfine levels. Two resonance lines were found, one at 121 mc and the other at 65 mc. The former was approximately twice as strong as the latter. While no definite identification of the transitions has been made, we assume that the higher frequency corresponds to the $F=4\rightarrow3$ and the lower frequency to the $3\rightarrow2$ transition. This assumption leads to values of "b" $=25\pm2$ mc and "a" $=25\pm0.5$ mc. The "a" is consistent with the known magnetic moment of Rb^{85}. The quadrupole moment of Rb^{85} calculated with the use of the fine structure separation of the Rb levels leads to the value of $Q_{Rb^{85}}=3.1\times10^{-25}$ cm² and from the known ratio of $Q_{Rb^{87}}/Q_{Rb^{85}}$[5] the quadrupole moment of Rb^{87} is 1.5×10^{-25} cm².

[1] I. I. Rabi, Phys. Rev. **87**, 379 (1952).
[2] Perl, Rabi, and Senitzky, Proc. Natl. Acad. Sci., **40**, No. 11 (A) (1954).
[3] Perl, Rabi, and Senitzky, Phys. Rev. **97**, 3 (L) (1955).
[4] Perl, Rabi, and Senitzky, "Nuclear electric quadrupole moment at Na^{25} by an atomic beam resonance method," Phys. Rev. (to be published).
[5] J. W. Trischka and R. Braunstein, Phys. Rev. **96**, 968 (1954).

G3. Nuclear Magnetic Moment of Potassium[39]. L. CARLTON BROWN AND DUDLEY WILLIAMS, *The Ohio State University.**—The nuclear magnetic resonance peak due to K^{39} in a saturated solution of KF has been observed in a field of approximately 7800 gauss. The K^{39} resonance frequency has been compared with that of N^{14} in a solution of HNO_3. The ratio obtained is $\nu(K^{39})/\nu(N^{14})=0.64588$, a value in agreement within the limits of experimental error with the value obtained by Collins,[1] who observed the K^{39} resonance in a solution of KNO_3. A comparison of the experimental errors will be given and a "best value" for the magnetic moment will be proposed.

* Supported by the Office of Scientific Research, Air Research and Development Command, U. S. Air Force.
[1] T. L. Collins, Phys. Rev. **80**, 103 (1950).

G4. Electron Capture Cross Section for Protons. C. F. BARNETT AND P. M. STIER, *Oak Ridge National Laboratory.*—Electron capture cross sections have been determined for protons passing through various gases in the energy range 20 to 250 kev. The proton beam from a Cockcroft-Walton accelerator was passed through a differentially pump gas cell in a transverse magnetic field. Neutral atoms formed by electron capture collisions do not follow the curved path of the ion beam and are not detected. From the exponential attenuation of the proton beam, the capture cross section is directly determined. Results will be presented for the capture cross section in hydrogen, helium, nitrogen, oxygen, neon, and argon. For energies greater than 80 kev the capture cross section varies as $\sigma_c=Ae^{-Bv}$, where A and B are constants for each gas, and v is the proton velocity. The cross section is the smallest for hydrogen being 20×10^{-17} cm² at 20 kev and 0.9×10^{-17} cm² at 200 kev. For argon the cross section decreases from 70×10^{-17} cm² at 20 kev to 1.12×10^{-17} cm² at 200 kev. The results are in agreement with those calculated from previously measured loss cross sections and the ratio of loss to capture cross section.[1]

[1] Stier, Barnett, and Evans, Phys. Rev. **93**, 926 (A) (1954).

G5. Self-Absorption or Self-Indication in the Nuclear Elastic Scattering Experiment.* E. G. FULLER AND EVANS HAYWARD, *National Bureau of Standards.*—A recent note[1] describing the elastic nuclear scattering of photons pointed out that the observed scattering cross sections below the particle threshold may require corrections for nuclear self-absorption by discrete energy levels. These corrections are required if the peak nuclear absorption cross section is greater than the electronic cross section. Thermal Doppler broadening reduces the peak cross section by approximately the ratio Γ/δ. Self-absorption has been observed by measuring the absorption of the target material for those photons which are elastically scattered. Self-absorption has been observed in Bi and Pb at 7 Mev, in Ni at 9 Mev, and in Al at 18 Mev. No appreciable effect was observed in Cu, Sn, or I. A "single level" analysis gives $\Gamma_\gamma/\Gamma\sim0.1$ for Bi, Pb, and Ni. The self-absorp-

tion corrections to the previously published scattering cross sections for the above nuclei will raise the cross sections at the energies indicated by about 15 percent.

* Supported by the Air Research and Development Command.
[1] Evans Hayward and E. G. Fuller, Phys. Rev. 95, 4, 1106 (1954).

G6. The $Li^6(p,d)Li^5$ Reaction.* J. G. LIKELY, *Princeton University.*—Deuterons from $Li^6(p,d)Li^5$ were observed on bombarding a Li^6 foil with 18.6-Mev protons. Particles passed through a proportional counter before stopping in a NaI scintillation counter. Proton background was eliminated by gating the NaI counter by pulse-height-selected proportional counter pulses having the correct size for deuterons at a particular energy. The $Li^6(p,d)Li^5$ ground-state group appears as a broad peak (1.8 Mev wide at half-maximum) which tails off to a low continuum at lower energies: from the maximum of the peak, $Q=-3.0\pm0.15$ Mev. While no other deuteron groups were observed, up to 6.5-Mev excitation in Li^5, the asymmetry of the main group (low-energy side) may suggest a broad level near the ground state. Deuteron background, possibly due to particle decay of Li^6 excited states, complicates the interpretation. The angular distribution of the main group rises to a peak at 15 degrees (center of mass) and, at small angles, conforms with Butler theory ($r_{\text{nucleus}}=5\times10^{-13}$ and $\ln=1$) but falls off more gradually than expected beyond 30 degrees.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.

G7. Mechanism of the Reaction $C^{12}+p\rightarrow p+3\alpha$ at 32 Mev.† JOHN LOGAN NEED, *University of California, Berkeley.*—A methane-filled expansion cloud chamber, operated at ½ atmosphere, was used to study the $C^{12}+p\rightarrow p+3\alpha$ reaction. Two hundred events that satisfied momentum and energy conservation were accepted for analysis. One hundred forty-eight of these had all four prongs visible; the remaining fifty-two had only three visible prongs with the fourth prong directed into an invisible region of the chamber. There is no evidence for the direct four-particle decay of N^{13*}. One-quarter of the events proceeded via the Be^8 ground state and at least one-half via the 2.9-Mev level in Be^{8*}; possibly higher levels in Be^{8*} were also involved. Evidence for the participation of levels in C^{12} at 9.6, 11.8, 16, 20, and 25 Mev was found. There are grounds for believing that the $C^{12}(p,\alpha)B^9$ reaction also participated with evidence for the ground state and the 2.4-Mev state of B^9. The possibility of the $C^{13}+p\rightarrow Li^5+Be^8$ reaction was investigated and it was concluded that it could account for at most five percent of the events.

† This work was performed under the auspices of the U. S. Atomic Energy Commission.

G8. Levels in Sc^{41}. H. S. PLENDL AND F. E. STEIGERT, *Yale University.*—A thin target of natural Ca prepared by evaporation from $CaCO_3$ onto a tantalum foil was bombarded with the 4.18-Mev deuteron beam. The neutrons were observed by proton recoils in Ilford C2 emulsions at angles of 0°, 30°, 45°, and 90° with respect to the incident beam. No-target exposures were also made to check the neutron background which was then subtracted out. Data from the 90° and 30° plates indicate a ground-state Q-value for the $Ca^{41}(d,n)Sc^{41}$ reaction of -0.60 ± 0.05 Mev. This is in excellent agreement with the value obtained using the energetics of the $Ca^{40}(d,p)Ca^{41}$ reaction[1] and the Sc^{41} β decay.[2] Additional groups are observed corresponding to six excited states in Sc^{41} at 0.62, 0.97, 1.13, 1.72, 2.10, and 2.34 Mev. Work is continuing on higher levels. Groups corresponding to the ground states of the $O^{16}(d,n)$ and $C^{12}(d,n)$ reactions are also observed and give an excellent check on the energy.

[1] Braams, Phys. Rev. 94, 763(A) (1954).
[2] D. R. Elliott and L. D. P. King, Phys. Rev. 60, 489 (1941).

G9. Nuclear Levels in V^{48} as Determined by the Decay of Cr^{48}.* JOSEPH R. WILKINSON AND RAYMOND K. SHELINE, *Florida State University.*—Chromium-48 has been produced by the 50-Mev alpha-particle bombardment of separated Ti^{46}, the nuclear reaction being $Ti^{46}(\alpha,2n)Cr^{48}$. Chromium-48 has previously been reported as a spallation product[1] with a half-life of 23 or 24 hr. No gamma radiation was reported for this nuclide. Our measurements of the half-life yields a value of 23 hr over a period of 5 half-lives. The gamma-ray spectrum of Cr^{48} has been investigated by scintillation techniques involving a 1½ in. ×1 in. NaI(Tl) crystal mounted on a DuMont 6292 tube. Gamma rays of 118 and 307 kev decaying with a 23-hr period have been observed. An apparent gamma ray of 431 kev is largely the sum peak of the 118 and 307-kev gamma rays, indicating a coincidence between these radiations. This information, together with the intensities of the gamma rays, the failure to observe positron radiation, or the accompanying annihilation gamma rays, allows the determination of a probable decay scheme for Cr^{48} and the consequent energy levels in V^{48}.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] Rudstam, Stevenson, and Folger, Phys. Rev. 87, 358 (1952).

G10. Coulomb Excitation of Energy Levels in Te and Ag. L. W. FAGG, E. A. WOLICKI, R. O. BONDELID, K. L. DUNNING, AND S. SNYDER, *Naval Research Laboratory.*—Several nuclei having ground-state spin ½ and therefore $\Omega=\frac{1}{2}^1$ have been studied by Coulomb excitation with protons and alpha particles. Using isotopically enriched metallic targets, first and second excited rotational states have been measured at 319 kev and 419 kev in Ag^{107} (96.8 percent) and 306 kev and 412 kev[2] in Ag^{109} (99.9 percent). A first excited state has been measured at 159 kev in Te^{123}. Evidence for the second excited state in Te^{123} and excited states in Te^{125} has been obtained. Calibrated I^{131} and Na^{22} sources have been used in determining excitation cross sections and associated quadrupole moments.

[1] A. Bohr and B. R. Mottleson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd 27, No. 16 (1953).
[2] With the exception of the 412-kev level in Ag^{109}, these values are in good agreement with the results of N. P. Heydenburg and G. M. Temmer, Phys. Rev. 95, 861 (1954).

G11. Polarization Measurement in the $D(d,p)H^3$ Reaction.† R. E. SEGEL AND S. S. HANNA, *The Johns Hopkins University.*—Thin targets of deuterium gas were bombarded with deuterons of 650-kev energy, and the protons entered a helium scattering chamber at an angle of 45° in the center-of-mass system. Protons scattered in the chamber were detected with two very thin NaI crystals placed at +90° and −90° (c.m.) to the proton direction. The polarization measurements were obtained by comparing the right-left scattering in helium gas to that in xenon. Background was determined by evacuating the scattering chamber. An additional determination of possible geometric asymmetry was obtained by rotating the scattering chamber through 180°. With the use of absorbing foils the measurements were performed at three different proton energies. Using the polarization parameters of Heusinkveld and Freier[1] for the $p-\alpha$ scattering, a polarization of (15 ± 10) percent was obtained for the D−D reaction at the bombarding energy used.

† Supported in part by U. S. Atomic Energy Commission.
[1] M. Heusinkveld and G. Freier, Phys. Rev. 85, 80 (1952).

G12. Electron Beam Extraction from an X-Band Microtron. H. F. KAISER, W. T. MAYES, AND W. J. WILLIS, *Naval Research Laboratory.*—Means for extraction of electrons using a general purpose X-band microtron[1] have been studied. This is possible by use of a magnetic shielding tube[2] placed in the magnetic field space to intercept a desired orbit half completed, thus allowing it to leave tangentially. A variety of such extractor probes have been studied experimentally and quite

different types give successful extraction. A conical-shaped tube with wall thickness decreasing to the electron ingress, first proposed,[2] was found less effective. Capture at the ingress is favored by sharp transition from field to no field but this increases distortion of the circular microton orbits near the probe. This distortion may be made more symmetrical using a probe in which electrons enter a slot on the side of a hollow cylinder extending across the field region. This offers the possibility of returning extracted electrons into the microtron to combine the extracted electrons to build up a circulating beam in an external guide field, thus forming the basis of a system whereby the microtron may be used as an injector for a large accelerator (conventional or strong-focusing synchrotron).

[1] H. F. Kaiser, Phys. Rev. 95, 667 (1954).
[2] Henderson, Heymann, and Jennings, Proc. Phys. Soc. (London) 66, 41, 654–664 (1953).

THURSDAY AFTERNOON AT 2:00

Federal Hill Room

(H. MEISSNER presiding)

Cryogenics; Fluid Dynamics

GA1. Superconducting Rhenium Alloys and Compounds. J. K. HULM, *Westinghouse Research Laboratories.*—In further studies of the superconductivity of arc-melted rhenium samples,[1] the addition of tungsten to rhenium in solid solution has been found to raise the superconducting transition temperature at the rate of about 0.4°K per atomic percent tungsten. The maximum value of T_c has not yet been determined, but it is known that the compound Re_3W_2, formed byond the limit of solid solubility, becomes superconducting at about 6°K. Other superconducting compounds of rhenium are Re_3B (2.8°K), Re_2Zr (6°K), and Mo_3Re (10°K).

[1] J. K. Hulm, Phys. Rev. 94, 1390 (1954).

GA2. Heat Capacity Measurements on Pure and Slightly Reduced Rutile (TiO_2) at Very Low Temperatures.* P. H. KEESOM AND N. PEARLMAN, *Purdue University.*—The Debye parameter in the true T^3 region of the specific heat (θ_0) of rutile is 758°K (9N degrees of freedom) and this region extends to above 4°K. Between 10 and 20°K θ decreases from 680 to 460°K. After slight reduction in H_2 or A at 1000°C, the heat capacity in the helium region increases greatly. Reversibility was shown by reoxidation. For not too great reduction, the additional heat capacity is constant in the helium region, and probably constant up to 13°K. Reduced rutile is a semiconductor and the electrons have a very high effective mass.[1] The Hall effect in rutile shows a maximum around 6°K and so Hall measurements did not lead to an independent estimate of the carrier concentration. A tentative explanation of the additional heat capacity assumes that each "free" electron contributes $3/2k$. The estimated degeneracy temperatures lead to a carrier mass of 350 m_e.

* Assisted by Signal Corps and U. S. Atomic Energy Commission contracts.
[1] R. G. Breckenridge and W. R. Hosler, Phys. Rev. 91, 793 (1953).

GA3. Atomic Heat of Graphite Between 1° and 20°K.* N. PEARLMAN AND P. H. KEESOM, *Purdue University.*—The atomic heat of pure artificial polycrystalline graphite has been measured between 1° and 20°K. Precautions were taken to ensure that no error was introduced by gas adsorbed on the graphite. The results agree very well with those recently reported by Bergenlid *et al.*[1] Below 2°K the atomic heat can be represented as the sum of a term proportional to T^3 arising from low frequency lattice waves and a term proportional to T due to electrons. These terms are about equal to 1°K where the total atomic heat is 6×10^{-5} joules/mole degree. The electronic term agrees in order of magnitude with that calculated from Wallace's band structure theory of graphite. Between 2 and 4°K the lattice atomic heat is proportional to T^3, as has been predicted from a consideration of the anisotropic graphite lattice. Between 10 and 20°K the atomic heat variation corresponds to a decreasing two-dimensional Debye θ, presumably corresponding to deviations from a linear vibration spctrum.[2]

* Assisted by U. S. Atomic Energy Commission and by Signal Corps Contracts.
[1] Bergenlid, Hill, Webb, and Wilks, Phil. Mag. 45, 851 (1954).
[2] H. B. Rosenstock, J. Chem. Phys. 21, 2064 (1953); J. P. Hobson and W. A. Nierenberg, Phys. Rev. 89, 662 (1953).

GA4. Contact Resistance between Superconductors and Normal Conductors. F. BEDARD AND H. MEISSNER, *The Johns Hopkins University.*—Measurements have been made of the contact resistance between two different superconductors and between a superconductor and a normal conductor. The measurements on the two superconductors were made at temperatures above the critical temperatures of both specimens, and also below the critical temperature of one of them, keeping the temperature constant and varying the current. The superconductor-normal conductor contacts were measured both above and below the critical temperature as a function of current. The high current (5 milliamperes) resistance, which is the sum of the channel resistances and the barrier resistance, was of the order of 0.1Ω. An asymmetry in the resistance with respect to current direction was sought for, but in most of the runs no evidence for this was found. Below the transition temperature of one of the contact materials, an abrupt drop in the contact resistance was observed at low values of current. This drop, in the case of Sn−Pb contacts at 3.81°K, went down to immeasurably small resistances. The resistance at 500 microamperes was in one case at least one thousand times smaller than the resistance at 600 microamperes.

GA5. A Theory of the Paramagnetic Effect in Superconductors.* HANS MEISSNER, *The Johns Hopkins University.*—F. London developed a theory for the transition to superconductivity of a cylinder through which a current flows. It is possible to extend this theory to the paramagnetic effect where a longitudinal magnetic field is superimposed in addition to the current. With the assumption that the ratio of the effective length to the effective diameter, l/a, of the superconducting particles is constant, this theory gives a paramagnetic effect in the transition region. The relative permeability $\bar{K}_m$ is a function of the ratio of the circular to the longitudinal magnetic field at the surface, i.e., of $\varphi_0 = H\varphi_0/H_{z0}$. However experiment shows that $\bar{K}_m$ is a function of $\gamma = \varphi_0(1-I_g/I)$, where I_g is a limiting current and I the total current. Good agreement with the experimental range of $\bar{K}_m$, however, is obtained when the theoretical value of φ_0 is replaced by γ.

* Supported by a grant of the National Science Foundation.

GA6. Oscillatory Hall Effect and Magnetoresistance of Bismuth.* JULES A. MARCUS, *Northwestern University.*—Brodie's measurements[1] of the Hall effect and magnetoresistance at 14°K have been extended to liquid helium temperatures using his best crystal, for which the residual resistance ratio is $R4.2°K/R0°C=1.7\times10^{-4}$. The magnetic field was perpendicular to both the trigonal axis and a binary axis while the current was in the direction of the trigonal axis. Superimposed on a monatonic decrease from −4000 emu at 3 kilogauss to −26 000 emu at 14 kilogauss is an oscillatory component of the Hall coefficient which is periodic in reciprocal field (as the susceptibility is in the de Haas van Alphen effect). The period and phase are the same as for the oscillating component of the magnetoresistance and give a value of $\beta/E_0=4\times10^{-4}$ gauss^{-1} for the dominant term. A component of twice this period is also present. While the absolute value of the mean Hall coefficient increases by a factor of 10 in going from 14°K to 4.2°K, it does not change between 4.2°K and 1.4°K. The amplitude of the Hall oscillations increases by a factor of 2 between 4.2°K and 1.4°K, but the magnetoresistance is constant in amplitude as well as mean value.

* Supported by the National Science Foundation.
[1] L. C. Brodie, Phys. Rev. **93**, 935 (A) (1954).

GA7. Flow Near the Leading Edge of a Flat Plate. J. A. LAURMAN AND S. A. SCHAAF.—The flow field in the immediate vicinity of the leading edge of a thin flat plate has been surveyed by means of a "free molecule probe." This is a wire stretched cross stream and used as a resistance thermometer. The diameter of the wire is small compared to the mean free path of the gas so that (1) the presence of the probe does not disturb the flow, and (2) its temperature is sensitively dependent on the local Mach number. Surveys were carried out at Mach numbers of 2 and 4. The boundary layer appears to grow linearly and there is a considerable region in which it coalesces with the shock wave. Some indication of slip is also apparent, particularly at the higher Mach number.

GA8. Velocity and Pressure Distributions in Turbulent Pipe Flow with Uniform Wall Suction.* H. L. WEISSBERG AND A. S. BERMAN, *Carbide and Carbon Chemicals Company, K-25 Plant.*—The effect of wall suction on the turbulent flow of air in a porous pipe was investigated for various flow and suction rates. Radial distributions of time averaged axial velocities and of the axial component of the turbulent velocity fluctuations were measured at various distances from the pipe entrance, using hot wire anemometry techniques. Distributions of pressure on the axis of the pipe were also observed. Increasing wall suction was observed to lower the radial component of the velocity gradient over most of the pipe cross section and to increase it in the vicinity of the wall. Turbulence levels were lowered, by the suction, over the entire cross section. Pressure drops in the axial direction were also lowered and the pressure was observed to rise in the direction of flow for sufficiently large suction rates. Some of these observations have been explained by means of a momentum equation derived from the time averaged equations of motion.

* Work done at the Oak Ridge Gaseous Diffusion Plant operated for the Government by Union Carbide and Carbon Corporation.

GA9. Reflection of an Acoustical Pressure Pulse from a Liquid-Solid Plane Boundary. T. W. SPENCER, *California Institute of Technology.*—The problem treated is concerned with predicting the transient response of a system, composed of a liquid layer bounded above by a vacuum and below by a perfectly elastic solid, when excited by an arbitrary pressure applied over the surface of a spherical cavity located in the fluid. The Laplace transform of the displacement response is expressed in terms of an integral which is expanded in such a way that each term describes the contribution from one of the image sources. Each term is evaluated exactly at points located on a vertical axis passing through the source. The final expression for the vertical displacement at axial points is composed of the acoustic, afterflow, and correction terms. In solids for which Poisson's ratio is greater than one third the initial variation of the correction is always toward positive values (corresponding to motion directed toward the interface). For Poisson's ratio less than one third the initial variation may be either positive or negative depending on the magnitude of the compressional velocity ratio. A surface wave is shown to exist regardless of the choice of parameters. The surface wave velocity is always less than it would be in the absence of the liquid.

THURSDAY AFTERNOON AT 2:00

Caswell Room

(J. S. KOEHLER presiding)

Irradiation Effects, II

H1. Changes in KCl Lattice Dimensions by Soft X-Rays. CHESTER R. BERRY, *Eastman Kodak Company.*—The lattice dimensions of powdered specimens of annealed and unannealed KCl were measured during irradiation by soft x-rays. One set of specimens was allowed to color during irradiation and another group was prevented from coloring by simultaneous white-light illumination. The following observations were made: There was an increase in lattice dimension during exposure for every specimen. No difference existed for specimens which were colored or not colored. Saturation in the change in lattice dimension occurred at a lower exposure for the unannealed specimens than for the annealed specimens. The total increase in lattice dimension was about $\Delta a/a=1\times10^{-4}$ for all specimens, compared with values given in the literature for maximum changes in length of approximately $\Delta l/l=20\times10^{-4}$. The difference indicates production of void volume, presumably Schottky defects. The failure to observe a difference between colored and uncolored specimens may be caused by a considerably larger production of Schottky defects than of color centers.

H2. Elastic Modulus of X-Irradiated Rock Salt.* R. B. GORDON AND A. S. NOWICK, *Yale University.*—Measurements of the room temperature dynamic elastic modulus (C_{11}) of x-irradiated NaCl crystals have been made to an accuracy of better than 0.01 percent. It is found that the modulus is unchanged by irradiation for well-annealed crystals, but may increase by as much as 5 percent in cold worked crystals. This modulus change is a volume effect. It is closely related to the modulus decrease on cold working, which occurs as a result of the production of dislocation segments oscillating in phase with the stress. The modulus of a freshly deformed crys-

tal increases with time because of the shortening of these segments. It is found that the x-irradiation of a deformed crystal raises the modulus by just the amount corresponding to the destruction of this dislocation contribution. The x-ray dosage required to saturate this modulus effect is very much smaller than that required to fully color the crystal. The irradiation time required to effect half the total modulus change is independent of the magnitude of the change. These results suggest that the effect of the radiation is to create new pinning points along a dislocation and that the rate at which a dislocation is attacked is independent of the density of dislocation lines.

* Work supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.

H3. Radiation Induced Coloring of Sodium Azide.* HYMAN ROSENWASSER,† *Picatinny Arsenal,* AND PAUL W. LEVY, *Brookhaven National Laboratory.*—The effects of radiation on powdered crystalline sodium azide (NaN_3) have been studied by optical reflection measurements. Gamma rays from a multi-Curie Co^{60} source produces a stable absorption band at 3600A and two poorly defined bands at 6600A and 7600A which decay at room temperature. The 3600A band also appears after a slow neutron and gamma-ray irradiation in the reactor animal tunnel facility which is near 30°C. The intensity of this band can be increased by cadmium shielding or decreased by leading shielding. In the reactor pneumatic tube facility, where the temperature is at approximately 100°C, and where the material is subject to fast and slow neutrons, another band is present at 6000A. The 6000A band becomes very intense relative to the 3600A band when sodium azide is bombarded by fast U^{238} fission neutrons (and associated gamma rays) even though the temperature is approximately 20°C.

* Work done under the auspices of the U. S. Atomic Energy Commission and Picatinny Arsenal.
† Guest Scientist, Brookhaven National Laboratory.

H4. Heat Treatment of Irradiated Sodium Azide.* RUSSELL W. DREYFUS,† *Picatinny Arsenal,* AND PAUL W. LEVY, *Brookhaven National Laboratory.*—The effects of heat treatment on sodium azide (NaN_3) subjected to various radiations have been studied. When a sample that has been irradiated with slow neutrons at 20°C is heated at approximately 90°C the formation and growth of the 6000A band is observed. This is the same band that appears when the material is subjected to fast neutrons at 20°C. For short anneals of equal time this band appears in slow neutron irradiated samples at 188°C but not in gamma-irradiated samples. However, when samples exposed to slow neutrons and/or gamma rays at temperatures <100°C are heated to $\sim$260°C a marked loss of reflectance appears in the 4000A to 10 000A region and another absorption band appears at 2800A. It is to be noted that heating unirradiated material to the same extent produces a reduction in reflectance of less than 10 percent of that observed in irradiated samples, at the wavelength of greatest change. It appears that the observed coloring is related to the decomposition of NaN_3 and that irradiation has greatly enhanced this process.

* Work done under the auspices of the U. S. Atomic Energy Commission and Picatinny Arsenal.
† Guest Scientist, Brookhaven National Laboratory. Private, U. S. Army.

H5. Reactor and Gamma-Ray Induced Coloring in Corning Fused Silica.* PAUL W. LEVY, *Brookhaven National Laboratory.*—The coloring induced by gamma-ray and reactor radiations in fused silicas from various manufacturers and in Brazilian crystalline quartz has been studied by optical transmission measurements in the region 2000A to 1 micron. Corning "purified" fused silica[1] shows practically no gamma-ray coloring while reactor irradiation produces a strong band at 2180A, a weak band at 2420A, and very slight coloring in the visible. In contrast, all other fused and crystalline samples we have measured show considerable gamma-ray and reactor coloring extending from 2000A through the visible, roughly similar to published spectra. Thus in the Corning material reactor, irradiations produce absorption bands not developed by purely ionizing radiation. Also, the rate and manner of coloring of the Corning material appears to be different from that of Brazilian quartz. The Corning silica may contain something which prevents it from being colored, or alternatively, the other silicas may contain impurities responsible for their coloring ability. A. J. Cohen[2] has made similar observations regarding the coloring of these materials by x-rays.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] The cooperation of Dr. J. W. Michener, Owens Corning Fiberglas Company, Newark, Ohio, who provided most of the Corning material, is sincerely appreciated.
[2] A. J. Cohen, J. Chem. Phys. (to be published).

H6. Long Wavelength Neutron Transmission as an Absolute Method for Determining the Concentration of Lattice Defects in Crystals.* J. J. ANTAL† AND R. J. WEISS, *Watertown Arsenal,* AND G. J. DIENES, *Brookhaven National Laboratory.*—It has been shown theoretically that neutrons of sufficiently long wavelength are scattered isotropically by isolated point defects and that this scattering can be measured when crystalline effects (Bragg scattering) are absent. Babinet's principle may be applied under such conditions and, therefore, vacancies and interstitials scatter in exactly the same manner. The cross section for this nuclear type of scattering is accurately known from other measurements. Thus, if the scattering from these defects is experimentally measurable an absolute method is at hand for determining their concentration. Some information on the agglomeration of these defects can also be obtained. It is not practical to measure directly the scattered neutron intensity. Instead, the attenuation of a long wavelength neutron beam during its passage through the material is measured in transmission. Transmission experiments will be presented on reactor irradiated α-Al_2O_3 which indicate that the number of defects can be measured by this technique with a rather high degree of accuracy.

* Work done under contract with the U. S. Atomic Energy Commission.
† Guest Scientist at Brookhaven National Laboratory.

H7. Magnetic Susceptibility of Fast Neutron Bombarded Crystalline Quartz. D. K. STEVENS, *Oak Ridge National Laboratory.*—The magnetic susceptibility of one unirradiated and two fast neutron bombarded piezo quartz cubes has been measured over the temperature range from 90°K to 300°K. The diamagnetic susceptibility of the unirradiated specimen was essentially temperature independent, while that of the irradiated specimens decreased markedly with decreasing temperature, indicating the introduction of paramagnetic centers. Curie plots of the values obtained by subtracting the unirradiated data from each of the irradiated curves yield straight lines, the slopes of which are proportional to the number of paramagnetic centers introduced. In the case of the cube subjected to a total nvt of 5×10^{19} cm^{-2} fast neutrons, 6×10^{19} paramagnetic centers, presumably trapped electrons, were present after irradiation. The second cube was bombarded with 3×10^{20} fast neutrons cm^{-2} but only 2.5×10^{19} paramagnetic centers were found. The density changes were -2 percent and -14 percent respectively.[1] The irradiated cubes were transparent but exhibited a faintly magenta coloration.

[1] M. C. Wittels and F. A. Sherrill, Phys. Rev. 93, 5, 1117 (1954).

H8. X-Ray Scattering Effects in Irradiated Boron Carbide. C. W. TUCKER, JR. AND P. SENIO, *Knolls Atomic Power Laboratory.**—Neutron irradiation of single crystals of boron carbide produces very strong x-ray diffraction effects. These are (1) *contraction* of the lattice in the c_0 direction and expansion in the a_0 direction; (2) an anisotropic artificial temperature factor which is six times as great in the c_0 direction as in the a_0

direction; (3) changes in the average lattice positions of certain atoms; and (4) very heavy diffuse scattering surrounding the reciprocal lattice points. Fourier analysis of the Bragg intensities shows that the anisotropy of the effects is due to the production of an anisotropic defect in the lattice during irradiation. This defect is identified as being due to the selective removal of the central carbon atom in a chain of three carbon atoms which lies parallel to the c_0 axis in the structure. Annealing experiments show that the selectively removed carbon atom becomes mobile in the temperature range of 700 to 900°C and finds its way back to its normal position. The x-ray effects can be understood qualitatively in terms of an elastic model of Huang. Work is in progress to extend the theory to the case of anisotropic defects.

* The Knolls Atomic Power Laboratory is operated by the General Electric Company for the U. S. Atomic Energy Commission.

H9. Optical Absorption Bands Induced in Gamma Irradiated Glass.* K. R. FERGUSON, *Argonne National Laboratory.*—The formation of optical absorption bands in glasses exposed to Co^{60} gamma rays has been observed. The wavelengths of these bands between 2000 to 20 000A are given for fused boric oxide, fused silica, and multicomponent glasses in the borosilicate, sodium silicate, barium silicate and phosphate systems. Bandwidths range from 0.6 to 1.5 ev. Certain bands reach an equilibrium density at room temperature after incident exposures of 10^7 roentgens; other bands are increasing in density after a 10^8 roentgens exposure. The fading of bands at elevated temperatures is greater for bands at longer wavelengths. The effect of additives in small amounts on the band structure of certain glasses is described.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

FRIDAY MORNING AT 9:30

Calvert Room

(J. M. LUTTINGER presiding)

DSSP Symposium on Spin-Orbit Effects in Solids

J1. Spin-Orbit Effects in Conduction Electron-Spin Resonance. Y. YAFET, *Westinghouse Research Laboratories.* (30 min.)

J2. The Ferromagnetic Hall Effect. R. KARPLUS, *University of California, Berkeley.* (30 min.)

Business Meeting of the Division of Solid-State Physics

J3. Theory of the Valence-Band Structure of Germanium and Silicon. C. KITTEL, *University of California, Berkeley.* (30 min.)

J4. Transport Effects in *p*-Type Germanium. A. C. BEER, *Battelle Memorial Institute.* (30 min.)

FRIDAY MORNING AT 9:30

Caswell Room

(J. A. BEARDEN presiding)

Mostly Nonmetallic Crystals

K1. Statistics for Electrical Phenomena. JOSEPH G. BARREDO, *Rocasolano Institute, National Council of Research, Madrid.*—Considering a dipole in line with a carrier as the most probable configuration of particles, a statistics is deduced by which it is possible to establish a unified theory of electrical phenomena. This theory embraces Ohm's and Coulomb's laws as particular cases, as well as other electrical phenomena which do not obey the Einstein-Bose or Fermi-Dirac distribution laws, e.g., overpotential, photovoltaic effect and semiconductivity. Because it takes cooperative effects into account more fully than the band scheme does, it also gives a more satisfactory description of superconductivity and provides a microscopic explanation of an electrical phenomenon predicted by a law of conductivity previously published and experimentally demonstrated.[1] However, the theory indicates that this effect should be called chronosuperconductivity rather than chronopolarography, as it was originally named,[1] because for small enough values of time the current is as large as the impedance of the measuring circuit will allow. The theory was demonstrated in diffused junction rectifiers and other states of aggregation with a precision oscillograph. The impedance of the oscillograph is low enough to prove that the recombination time for the hole+electron→bound electron $<2.10^{-9}$ sec.

[1] J. G. Barredo, Phys. Rev. **83**, 234 (1951); J. Chem. Phys. **19**, 1065 (1951); Bull. Am. Phys. Soc. **29**, No. 7, 14 (1954).

K2. Computation of Electron Density and Density of States in Narrow Bands in Crystals.* G. W. LEHMAN, *North American Aviation, Inc.* (introduced by D. B. Bowen).—A method for obtaining the electron density and density of states associated with narrow energy bands in crystals has been developed. This method avoids the usual eigenvalue-eigenvector problem. The crystal wave function is expanded in terms of Bloch functions associated with the appropriate linear combination of atomic orbitals. Using this representation one can show that the summation over states involved in finding the electron density in the narrow band approximaiton reduces to a calculation of matrices defined by Tchebichef polynomials. The procedure is being used for calculating a density of states curve for the $6d_{3/2}-6d_{5/2}$ band in fcc thorium.

* This work supported by the U. S. Atomic Energy Commission.

K3. Localized States at the Boundary of Two Crystals.* GEORGE W. PRATT, JR., *M.I.T.*—The solution of Schrodinger's equation at the interface between two different crystals has been investigated. Under certain condixions localized states are found to exist at the boundary with energies lying in a mutual energy gap. A nearly free electron treatment of the problem results in either one localized state per boundary atom or none at all. The appearance of a localized state is accompanied by the disappearance of a band state from either side of the common energy gap.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

K4. Determination of Dislocation Densities with the Double Crystal Spectrometer.* A. D. KURTZ, S. A. KULIN, AND B. L. AVERBACH, *M.I.T.*—Random dislocation densities may be determined from precise values of the diffracted line breadth using the formula $\rho=\phi^2/9\lambda^2$ [1] where ρ is the edge-type dislocation density, ϕ is the half-breadth of an x-ray diffraction line, and λ is the interatomic distance on the slip plane. Line-breadths are obtained from rocking curves measured on an x-ray double-crystal spectrometer used in the parallel position. Measured broadening must be corrected for the broadening contribution of the first crystal. By assuming different Gaussian reflection coefficients for each crystal, the measured broadening can be expressed in terms of broadening functions for each crystal. The diffracted power $P_{(\beta)}$ at any angular setting β is shown to be: $P_{(\beta)}=C\exp[-\beta^2/(\phi^2+K^2)]$, where C is a constant and K and ϕ are the true half-breadths of the first and second crystals respectively. K is determined from a rocking curve in which the second crystal is identical with the first. Having determined K, the value of ϕ (the true half-breadth) may be obtained for each crystal studied and the dislocation density calculated from the above formula. Other possible sources of error in measurement of rocking curves using the x-ray double crystal spectrometer are also analyzed.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
[1] Gay, Hirsch, and Kelly, Acta Met. 1, 315 (1953).

K5. Polytypism and Dislocations. N. CABRERA AND M. M. LEVINE, *University of Viriginia.*—Frank[1] explained some years ago the growth of polytypes (crystals having a structure with a slightly higher free energy than the most stable one), particularly in SiC, on the basis of the dislocation theory of crystal growth. His theory should be applicable in general, and the problem remains to understand why polytypism is not more frequent. This paper is an attempt in this direction based on the following ideas: (1) Dislocations are introduced by collisions between perfect crystal nuclei. Only particular disorientations between the crystals will allow the dislocations in the resulting grain boundary to induce further growth of either the stable phase or one of the possible polytypes. (2) The permanence of a given polytype will depend on the mechanism of transformation to the stable phase. The dislocation theory of mutual transformation of lattices permits one to reach conclusions concerning the stability of the polytypes. The theory has been developed particularly for close-packed structures.

[1] F. C. Frank, Phil. Mag. (London) 42, 1014 (1952).

K6. Polarization in Insulating Crystals.* CAPUCINE AND NICOLAS INCHAUSPÉ, *University of Illinois.*—An elementary analysis has been made of the problem of the development of space-charge within an illuminated insulating crystal which exhibits photoconductivity. The analysis is applicable to crystals similar to alkali-halides in which the displacement, w, of the photoelectrons by the field is much smaller than the distance, d, between the electrodes. The analysis has been carried out for various types of nonuniform illumination in the form of a plane parallel condenser. The initial slope of the photocurrent time curve is given by $(1/i_0)(di/dt)_0=(d/a)(i_0/q_0)$, where i_0 is the initial current and q_0 is the charge of the condenser before illumination. The length, a, characterizes the nonuniform illumination and is a measure of the distance within which the radiation is absorbed.

* Partially supported by the Office of Scientific Research.

K7. Creation of a Potential Difference across NaCl Crystals by Deformation.* D. B. FISCHBACH AND A. S NOWICK, *Yale University.*—A study has been made of the flow of current at room temperature through NaCl crystals deformed in compression. A sensitive vacuum tube electrometer is used to measure the potential drop across a 10-in. ohm resistor connected across the crystal. When the crystal is deformed inhomogeneously a transient potential difference is developed such that the side of the crystal which has the higher stress concentration becomes negative. If the load is left on, this potential decays to zero over a period of minutes in roughly a hyberbolic fashion. Removal of the load at any time drops the current flow to zero almost instantaneously. Reapplication of the same load produces a new transient current in the same direction as the original flow, but smaller in magnitude. The direction of the initial current flow is unaffected by externally applied fields as large as ± 1000 volts/cm. A discussion of the possible interpretation of this effect will be given.

* Work supported by the U. S. Air Force through the Office of Scientific Research of the Air Research and Development Command.

K8. Self-Diffusion of Silver in Silver Chloride.* W. DALE COMPTON, *University of Illinois.*—The self-diffusion of silver in AgCl was measured over a temperature range of 100° to 417°C on two single crystals and two polycrystals using the Ag^{110} radioisotope. No significant variation in the diffusion coefficient was detected in these crystals in the intrinsic region where they can be represented by $D_{Ag}=1.23\exp(-0.90/kT)$ cm^2-sec^{-1}. Electrical conductivity measurements were made on the above crystals over a temperature range of 30° to 428°C. The purity was such that the knee in the conductivity *vs* $1/T$ curve occurred between 60° and 130°C. An appreciable variation in the intrinsic conductivity was found among these crystals. As in AgBr, an anomalous rise in the conductivity occurs above 390°C. The measured diffusion coefficients in the intrinsic region were found to lie significantly below coefficients calculated from the Einstein-Nernst relation. No explanation for this discrepancy can be given at this time.

* Supported in part by a National Science Foundation grant.

K9. Extreme Ultraviolet Absorption Spectrum of Silver Chloride.* CHARLES J. KOESTER AND M. PARKER GIVENS, *University of Rochester.*—The absorption spectra of evaporated thin films of silver chloride have been measured in the extreme vacuum ultraviolet region, 500–1500A. A grazing incidence spectrograph with a Lyman type discharge tube has been used. Thicknesses of the sample films, ranging from 50 to 200 A, were determined by multiple-beam interferometry, as described by Tolansky.[1] The linear absorption coefficient generally increases with decreasing wavelength until a rather broad maximum is reached in the vicinity of 1000 A, where it is the order of 10^6 cm^{-1}. The decrease at shorter wavelengths is slight.

* Research formerly supported by the Office of Naval Research and more recently by the National Science Foundation.
[1] S. Tolansky, *Multiple-Beam Interferometry of Surfaces and Films* (Oxford University Press, New York, 1948).

K10. (Abstract withdrawn.)

K11. Light Scattering from Optical Glass. R. D. MAURER, *Corning Glass Works.*—A Brice-Phoenix light scattering photometer has been modified to enable measurement of the small intensity scattered from optical glass. Particular attention has been given to the angular distribution of scattered intensity. Dissymmetry, depolarization, and relative Rayleigh's Ratio have been measured on fifteen types of commercial optical glass. All the glasses showed dissymmetry of scattering with dissymmetry values (I_{45}/I_{135}) ranging from 1.02 to 1.24. The scattered intensity was evaluated by comparison with benzene and found to be much greater than the calculated room temperature thermal scattering. The dissymmetry and scattered intensity both indicate the presence of frozen-in inhomogeneities. Further implications of the measurements will be discussed.

K12. Conduction in Phthalocyanine Crystals.* D. KLEITMAN AND G. GOLDSMITH, *Purdue University.*—Thin films and needlelike single crystals (as indicated by Laue patterns) of phthalocyanine were grown by vacuum sublimation from Dupont commercial grade phthalocyanine and from material purified by a prior fractionating sublimation. Dark conduction in the crystals was measured as a function of field and temperature. Conduction was ohmic to fields of 2000 v/cm. The temperature behavior indicated that the relation $\sigma=\sigma_0 \exp(-E/kT)$ applied between room temperature and 420°C. The results were reproducible and independent of applied field and helium pressure, with either silver paste or aquadag electrodes, for any particular crystal. For different samples the E-values ranged between 0.7 and 1.0 ev, and could be altered in a sample by heating to temperatures greater than 420°C. Defects in the crystal structure or impurity effects might account for this behavior. Films were found sensitive to atmospheric effects and temperature behavior of the conductivity was not reproducible. Photoconductivity was observed in both films and crystals. No saturation was indicated and ohmic behavior observed. The transmissivity of films and the dependence of photoconductivity on wavelength was measured over the visible range and to 1 micron. Similar behavior was observed with copper phthalocyanine films and crystals.

* Supported by a Bureau of Ships contract.

K13. Prismatic Slip in Crystals. J. W. DAVISSON, ELIAS BURSTEIN, AND P. L. SMITH, *U. S. Naval Research Laboratory.*—Prismatic slip has been observed in crystals of the cubic, tetragonal, and orthorhombic systems. The crystals, which are all holohedral, are: cubic NH_4Cl, NH_4Br, CsCl, CsBr, TlCl, TlBr, and PbS; tetragonal $PbCO_3 \cdot PbCl_2$; and orthorhombic $ZnCl_2 \cdot 2NH_3$. The prisms observed are [001] (100) and [001] (110). We have also recently observed prismatic slip in tetragonal tin. Galena (PbS) and tin furnish examples of competing slip systems. Thus galena exhibits both nonprismatic and prismatic slip of the forms [110] (001) and [001] (100) and tin exhibits two forms of prismatic slip [001] (100) and [001] (110). In one specimen of galena we have observed only nonprismatic punch figures on one cleavage face and only prismatic punch figures on a cleavage face situated at right angles to the first. In tin the prismatic slip observed at low temperatures is [001] (100) rather than [001] (110) which, according to published data,[1] corresponds to a lower critical shear stress. These effects in galena and tin may be due to preferential strain hardening of one set of the glide elements.

[1] I. Obinta and E. Schmid, **Z. Physik 82**, 224 (1933).

FRIDAY MORNING AT 9:30

Founders' Room

(L. MADANSKY presiding)

Luminescence

L1. On the Theory of Electroluminescence, BRIAN T. HOWARD, *Westinghouse Electric Corporation* (introduced by E. G. F. Arnott).—On the basis of the mechanism proposed by Piper and Williams[1] an analysis is made of the voltage dependence of electroluminescence. It is assumed that electrons are removed from deep donors in the region of a Schottky-type potential barrier by the process of internal field emission. These electrons are subsequently accelerated, acquiring sufficient kinetic energy to excite activator centers by impact ionization. The relationship used for the field dependence of the process of field emission from the donors is that derived by Franz.[2] The electroluminescent brightness is a function of the distribution in depth and in energy of the donors and of the efficiency of the impact ionization process. The problem is set up in a general form and several analyses made utilizing specific assumptions. The available experimental data is best fitted using the simplest assumptions possible leading to a voltage dependence of the form $L=aV^{\frac{1}{2}}(1-3V^{\frac{1}{2}}/C)\exp(-C/V^{\frac{1}{2}})$. The analysis is subsequently extended to the frequency dependence of electroluminescence on the basis of an equivalent circuit composed of nonlinear elements.

[1] W. W. Piper and F. E. Williams, Phys. Rev. **87**, 151 (1952).
[2] W. Franz, Ann. d. Phys. **11**, 17 (1952).

L2. Temperature Dependence of Electroluminescence, CLAUS H. HAAKE, *Westinghouse Electric Corporation,* (introduced by H. Fivey).—The electroluminescent brightness of a cubic ZnS·Cu·Pb phosphor was measured at constant voltage

and constant frequencies over a temperature range of −180°C to +150°C. The powder was inserted in a plaque cell. At each temperature the electroluminescent brightness I_{el} and the fluorescent brightness I_f excited by 3650 A was read. The I_{el}-curves resemble glow curves, as has also been reported by other workers.* However, a glow curve taken with this phosphor proved to be completely different from the I_{el}-curves. The ratios of I_{el} and I_f were determined yielding the temperature dependence of the excitation mechanism of electroluminescence (I_{es}). It was found that I_{es} can be given as a sum of exponential functions with $-E_i/kT$ as exponents. The E_i-values equal the activator heights above the valence band, since about the same values were obtained by evaluation of I_f. Increasing frequencies shift the I_{el}-curves to higher temperatures. The equation describing this phenomenon is similar to that obtained by Alfrey and Taylor; contrary to their assumptions the activation energies are not identical with trap depths. The spectral emission shift in two-band phosphors with increasing frequencies can be explained; increasing frequency acts like decreasing temperature.

* Gobrecht, Hahn, and Gumlich, Z. Physik **136**, 623 (1954).

L3. Polarization Effects on the Brightness Waves of Electroluminescence. FRANK MATOSSI, *U. S. Naval Ordnance Laboratory.*—Electroluminescence excited by sinusoidal fields yields two maxima per half period of the field. The intensity ratio of these maxima depends on the field frequency and on the superposition of ultraviolet excitation. These observations are shown to be related to the existence of polarization effects, which are treated by extending previous theories of such effects in semiconductors (Jaffe and others), taking into account periodic excitations of centers by the field.

L4. Stacked Barriers in an Electroluminescent Zinc Sulfide Crystal. E. E. LOEBNER AND H. FREUND,* *Sylvania Electric Products, Inc.*—Electroluminescence was produced in a single, needle-like, 2-mm long crystal of zinc sulfide, which was excited by a sinusoidal, 1000 cps electric field of a low magnitude. The blue radiation appears under the microscope as clusters of luminous spots. These spots are no more than a few microns large and their mean separation within a cluster is about 30 microns. Scanning the crystal's length (in the direction of the applied field), it was found that sharp light pulses of a 1000 cps repetition rate and about 100 μsec duration, which are emitted from the spots, change their phase with respect to the excitation voltage when one moves from spot to spot. More than four reversals of 180° were found along the 1½-mm luminescing length of the crystal, some of them at points separated by as little as 40 microns. These observations are consistent with those of previous investigators, but permit new insight into the mechanism of electroluminescence in zinc sulfide crystals, and show that probably an internal barrier rectification is present.

* Now at Roswell Park Memorial Institute, Buffalo, New York.

L5. Effects of Electric Fields on Ultraviolet Excited ZnS-Phosphors. SOL NUDELMAN AND FRANK MATOSSI, *U. S. Naval Ordnance Laboratory.*—Electroluminescent and non-electroluminescent ZnS phosphors excited by continuous ultraviolet radiation undergo sudden stimulations at the instants of field application and removal and a quenching during the time of field application. Quantitative data about field and frequency dependence of stimulations and quenching are given. The stimulation at "field on" decreases with frequency up to about 20 kcps and then either remains constant or slightly increases up to 100 kcps. The stimulation at "field off" increases with frequency. For electroluminescent phosphors, the brightness waves of electroluminescence are compared with the ripple pattern of the quenching effect. For some phosphors, the number of intensity peaks during one half-period of the field depends on the superposition of field and ultraviolet excitation. The gradual transition from ripple to brightness wave for increasing field strength will be shown for sinusoidal and square wave fields. These transition curves demonstrate that quenching effects and electroluminescence have independent origins.

L6. Origin of Luminescence in Copper Activated ZnS Phosphors. NATHAN T. MELAMED AND RAYMOND BOWERS, *Westinghouse Research Laboratories.*—Five different emission bands have been reported in the literature for ultraviolet excited zinc sulfide, activated by varying concentrations of copper and/or chlorine. Emission spectra and static susceptibility measurement were obtained at various temperatures on specimens chosen to optimize each of the five emissions. Susceptibility measurements were carried out over a range from 1.5°K to room temperature by means of a Gouy balance, whose sensitivity was sufficient to detect a paramagnetism corresponding to less than 10^{-6} atomic parts of paramagnetic copper. No paramagnetism was detected in any of the specimens. Of the five emissions reported, only three are found to be distinct: a blue emission due to chlorine alone, a green emission due to the presence of both chlorine and copper, and a red emission due to copper without chlorine. The blue emission has previously been attributed to zinc vacancies produced by the chloride.[1] On the basis of the susceptibility measurements, and because the same blue emission occurs in specimens having a red emission, but containing copper without chloride, it is probable that the green emission results from substitutional Cu^+ whereas the red emission arises from interstitial Cu^+.

[1] F. A. Kröger and H. J. Vink, J. Chem. Phys. **22**, 250 (1954).

L7. Dielectric Dispersion in Zinc Sulfide Phosphors.* I. AMES, H. S. SACK, AND R. M. WOOD, *Cornell University.*—Dielectric relaxation has been reported by several authors[1] for ZnS phosphors under illumination. The present experiments extend the measurements to compressed and sintered powders, and to single crystals. The samples were mounted between semitransparent gold plated electrodes and the impedance was measured under 3650 A excitation at 90 and 300°K, from 30 cps to 20 msec. Relaxation was observed for hexagonal samples which luminesced. Larger relaxation times were found for crystals and compressed-sintered samples than for powders. The intensity and temperature dependence of the relaxation, when present, was similar for all samples, and was consistent with the grain boundary model. Upon compression of a luminescent hexagonal powder, the relaxation effect disappeared, and then reappeared after sintering. X-ray analysis revealed that this procedure altered the lattice structure from hexagonal to cubic, to partially hexagonal. The absence of relaxation for cubic samples suggests that internal inhomogeneities in the hexagonal structure are responsible for the phenomena.

* Supported by the Research Corporation of America.
[1] G. F. J. Garlick and A. F. Gibson, Proc. Roy. Soc. (London) **A188**, 485 (1947); R. M. Wood, thesis, Cornell University (June, 1953); J. J. Dropkin, Polytechnic Inst. of Brooklyn Reports (May, 1952; November, 1953); Kallmann, Kramer, and Perlmutter, Phys. Rev. **89**, 700 (1953).

L8. Model for Luminescence and Photoconductivity in the Sulfides. JOHN LAMBE AND CLIFFORD C. KLICK, *U. S. Naval Research Laboratory.*—A model for sulfides activated by monovalent metals is discussed which differs in several important respects from that usually employed. Because of the net negative charge of the lattice volume surrounding the activator there is a large cross section for trapping of holes which may be accompanied by release of a large amount of energy. This is presumed to be the transition leading to luminescence. A subsequent trapping of an electron returns the center to its original condition. For the electron trapping there is no coulomb field and both the capture cross section

and energy released would be expected to be small compared with the case of hole trapping. On the basis of this model, there is a simple explanation of the fast luminescence decay associated with hole capture and the slow conductivity decay associated with that of free electrons. Other well-known phenomena in the sulfides are examined on the basis of this model. In addition, predictions of this model concerning the infrared photoconductivity and infrared stimulation of luminescence have been verified by experiment on silver activated cadmium sulfide.

L9. Storage of Energy in Beryllium Oxide.* C. E. MANDEVILLE AND H. O. ALBRECHT, *Bartol Research Foundation.*—The photostimulated ultraviolet emission of x-ray excited BeO has been measured as a function of the wavelength of the incident light. A maximum of emission occurs for a stimulating wavelength of ~4100 A. Experiments are described which are interpreted as showing the presence of doubly occupied traps in BeO which are analogous to the *F*-centers of the alkali halides. Some discussion concerning energy storage in NaCl–Ag will also be presented.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

L10. Influence of an Electric Field on the Thermoluminescence of ZnS Crystals. GERTRUDE NEUMARK, *Sylvania Electric Products Inc.*—We have noticed on a number of electroluminescent ZnS crystals that the application of a strong dc electric field during thermoluminescence considerably increases the intensity of the light emitted over the sum of the intensities due to thermoluminescence and electroluminescence separately. For one crystal, at a field of 5000 v/cm, the thermoluminescence with field minus the electroluminescence was larger than the thermoluminescence without field by a factor of 3 at −180°C to −150°C, increasing steadily to a factor of 12 at −70°C, above which there was negligible thermoluminescence. We believe that the increase in light output is due to impact ionization of bound electrons by the electrons thermally released from the traps and then accelerated by the field. The gain in sensitivity due to the increased light output has also helped to show that an electric field can be used as excitation for obtaining thermoluminescence.

L11. Low Temperature Luminescence in KCl:Tl. D. A. PATTERSON AND C. C. KLICK, *U. S. Naval Research Laboratory.*—Measurements on the two principal emission bands of KCl:Tl have been extended to 4°K. The decrease in half-width of the 3050 A band with temperature was found in excellent agreement with that obtained from Williams'[1] curves for the $^1S_0$ and $^3P_1^0$ electronic states of Tl+. An emission band at 4750 A, ascribed by Johnson and Williams[2] to a $^1P_1^0$ to $^1S_0$ transition, has been found to have an intensity relative to the 3050 A emission which agrees with their predicted value. With two close-lying excited states involved, it is uncertain which of their intersections with the ground state curve leads to the observed quenching of luminescence with temperature. This also points out a difficulty in the general use of temperature quenching data in the development of configuration coordinate curves from experiment.[3]

[1] F. E. Williams, J. Phys. Chem. **57**, 780 (1953).
[2] P. D. Johnson and F. E. Williams, J. Chem. Phys. **20**, 124 (1952).
[3] C. C. Klick, Phys. Rev. **85**, 154 (1952).

FRIDAY MORNING AT 10:30

Federal Hill Room

(W. F. G. SWANN presiding)

Cosmic Rays

M1. Results of Limitations on Space Current Densities in Galactic and Intergalactic Space.* W. F. G. SWANN, *Bartol Research Foundation.*—The high electrical conductivity of space has raised difficulties in mechanisms concerning the production of cosmic-ray energies. High conductivity does not avoid limitation of the current density, i, to the value nec where n is the sum of the numbers of positive and negative ions per cc. Thus, for $n=1$, the saturation current density is of the order 5×10^{-9} ampere/cm². The effect of saturation is illustrated by the following idealized example. Consider two coplanar rings of gas A and B, A being the smaller. Under high conductivity, it would be impossible for the magnetic flux through either circuit to change and the electric field would be zero. If B expands, the flux through A caused by B changes, but A acquires induced current to compensate the change. As time proceeds, and if the ionic density in A is small, a stage will be reached at which A can no longer develop the current necessary for magnetic flux compensation. An electric field will now arise in A and the ions will become accelerated to cosmic-ray energies, not by appreciable alteration of velocity which has already attained its maximum c, but by alteration of relativistic mass.

* Assisted in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

M2. Experiment for Determining the Anisotropy of Primaries.* K. Y. SHEN AND S. F. SINGER, *University of Maryland.*—From theoretical arguments[1] it was proposed that simple telescope arrangements should be effective in making extensive air shower equipment highly directional, i.e., sensitive to showers coming in from a certain direction in the sky. This scheme is particularly appropriate for the zenith case at sea level where the atmosphere acts to attenuate showers at large zenith angles. For other directions the method becomes more involved. The apparatus will be described together with experimental results about its directivity. One of the important applications of this technique is to the study of the anisotropy of ultra high energy primaries. The experiment consists of a search for a sidereal diurnal time variation. Two further refinements are incorporated into the experiment: (1) Events produced by high energy primaries are selected by demanding high particle density. (2) High counting rates, therefore good statistics, are obtained not by increasing the size of the detector, but by setting up a large number of identical stations at some distance from each other.

* This work is supported by the National Science Foundation.
[1] S. F. Singer, thesis, Princeton University. (1948).

M3. The Albedo Contribution in the Measurement of Cosmic-Ray Primaries.* R. C. WENTWORTH AND S. F. SINGER, *University of Maryland.*—The major uncertainty in the determination of the primary proton spectrum lies in the evaluation of the effects of albedo. A number of experiments[1,2] have shown that the albedo contribution has a minimum in

the vertical direction, but could not assign a value to it. This vertical minimum seems plausible by simple theoretical arguments. We have made a calculation of the "splash" albedo moving vertically upward near the top of the atmosphere at $\lambda = 56°$, using data from balloon emulsions and high energy accelerators. The results are compared with recent experiments.[3] The difficulties inherent in our calculation and in the experimental approach are discussed. A time-of-flight telescope would give data of great value about upward-moving albedo. We are extending our theoretical treatment to include the effects of geomagnetic albedo in an approximate way.

* Supported in part by the Office of Scientific Research, U. S. Air Force.
[1] S. F. Singer, Phys. Rev. **77**, 729 (1950); **80**, 47 (1950).
[2] J. A. Van Allen and A. V. Gangnes, Phys. Rev. **78**, 50 (1950); **79**, 51 (1950).
[3] J. R. Winckler and K. Anderson, Phys. Rev. **93**, 596 (1954).

M4. A New Method for Measuring the Low Energy Spectrum of Primary Cosmic Rays. S. F. Singer, *University of Maryland.*—Measurements of the primary spectrum with balloons and also rockets suffer from the contribution of unknown amounts of albedo. High latitude measurements have established a "knee" in the spectrum caused by the marked paucity of primaries with momentum/charge less than 1.5×10^9 volts. Their actual number is unknown but would be of great importance for our understanding of the relation of cosmic rays to events in the solar system. Present high latitude measurements may be inherently unsuitable because of complicating effects of the earth's quadrupole field and our inadequate knowledge of the shadow cone. An entirely different approach lies in measuring the cosmic ray intensity at the geomagnetic equator as a function of altitude starting at the top of the atmosphere, surmounting the cosmic ray "plateau" and extending the measurements to extreme distances from the earth. A preliminary calculation of the expected intensity variation with altitude has been carried out for the equatorial case, using geomagnetic theory and taking into account the geomagnetic shadow of the earth. The results demonstrate the potentialities of the proposed method for determining accurately the primary cosmic ray spectrum down to energies well below the "knee," away from albedo effects and distortions of the magnetic dipole field near the earth.

Post-Deadline Papers, if Any

Friday Morning at 9:30

Phoenix Room

(J. D. Ferry presiding)

Invited Papers of DHPP

MA1. Statistical Calculation of Dimensions of Coiling Type Macromolecules. F. T. Wall, *University of Illinois.* (30 min.)

MA2. X-Ray Diffraction Studies of Crystallization in Elastomers. L. E. Alexander, *Mellon Institute.* (20 min.)

MA3. Stress-Optical Studies on Amorphous and Polycrystalline Elastomers. G. R. Taylor, *Mellon Institute.* (20 min.)

Contributed Papers in High-Polymer Physics

MA4. Apparatus for Making Simultaneous Stress and Birefringence Measurements on Polymers. E. F. Gurnee, L. T. Patterson, and R. D. Andrews, *The Dow Chemical Company.*—An instrument has been constructed to allow simultaneous measurements of stress and birefringence in polymer samples to be made as a function of time and temperature. The stress is measured by attaching one end of the sample to a cantilever beam; the small deflection of the beam is indicated by means of a differential transformer, which in turn is attached to an automatic recorder. The birefringence is measured with a Senarmont compensator (quarter-wave plate method). Measurements can be made either manually or with a continuously rotating analyzer. This latter method permits the automatic recording of the birefringence and is also adaptable to the study of rapid birefringence changes. The sample is housed in a copper pipe surrounded by a thermostatically controlled liquid bath. Some data are presented showing the use of this apparatus in measuring birefringence and stress changes during stress relaxation experiments (sample held at constant elongation), birefringence changes during creep under constant load, and stress-optical coefficients.

MA5. Retraction of Oriented Polystyrene Monofilaments. R. D. Andrews, *The Dow Chemical Company.*—When oriented polystyrene monofilaments are heated to temperatures in the neighborhood of the transition temperature they retract to an unoriented state at measurable rates. Curves of length as a function of time have been measured at five different temperatures (75°–95°C, at 5° intervals) for two filaments with different initial amounts of orientation. When the retraction curves are plotted as length *vs* log time, it is found that the curves at different temperatures are not superposable by lateral shift along the logarithmic time scale, as would be true in the simplest case. Activation energies calculated from these curves are a function of time as well as of temperature; the activation energy values at any given temperature tend to level out to final constant values with increasing time, however. The rate of change of activation energy value with time increases with increasing temperature, so that the final value is attained more quickly; the final value also decreases systematically with increasing temperature. Activation energy values increase rapidly with decreasing temperature in this region and are very high (300 kcal at 75°). It is postulated that specific volume changes are responsible for the time-dependent activation energies observed in these experiments.

MA6. Infrared Spectrum and Structure of Polyvinylidene Chloride. S. Krimm and C. Y. Liang, *University of Michigan.*—The infrared spectrum of polyvinylidene chloride has been obtained between 2.5 and 100μ. Polarization measurements

from 2.5 to 33μ were made on an oriented copolymer with polyvinyl chloride containing over 85 percent polyvinylidene chloride. The similarity of the two spectra permitted unambiguous correlation with the bands of the pure polyvinylidene chloride. The detailed structure of this polymer is not as yet known. X-ray diffraction studies have indicated a fiber-axis identity period containing two monomer units, for which two possible chain configurations have been proposed.[1,2] The interpretation of the infrared spectrum also requires that there be at least two monomer units in the repeat, and indicates that the spectrum is consistent with the Fuller structure[1] but not with the Reinhardt structure.[2] A helical model appears to be eliminated. On the basis of the Fuller structure, and by analogy with the spectra of smaller molecules, a fairly complete assignment of the infrared bands has been made.

[1] C. S. Fuller, Chem. Rev. **26**, 143 (1940).
[2] R. C. Reinhardt, Ind. Eng. Chem. **35**, 422 (1943).

MA7. Normal Vibrations and Infrared Spectrum of Polytetrafluoroethylene. C. Y. Liang and S. Krimm, *University of Michigan.*—The infrared spectrum of polytetrafluoroethylene between 2.5 and 100μ has been obtained, and the dichroism of oriented film observed between 2.5 and 33μ. On the basis of the helical structure recently proposed for this polymer,[1] the symmetry species and selection rules for the normal vibrations have been derived from the factor group of the one-dimensional space group. Approximate vibrational patterns of the active fundamentals have been deduced from symmetry considerations. From this analysis, the polarization and approximate intensities of the allowed infrared active fundamentals have been predicted. A calculation of the fundamental frequencies of a hypothetical planar zig-zag chain model of polytetrafluoroethylene has been made in order to assist in the assignment. Although the observed infrared spectrum definitely excludes the possibility of a planar zig-zag configuration, it may be assumed that the infrared frequencies for the helical model will be close to the frequencies of the planar model. By using these various approaches, a satisfactory assignment has been made of the infrared active fundamentals of polytetrafluoroethylene.

[1] C. W. Bunn and E. R. Howells, Nature **174**, 549 (1954).

MA8. Nuclear Spin-Spin Relaxation Time in Polymers. E. M. Banas and B. A. Mrowca, *University of Notre Dame.*—Nuclear magnetic resonance absorption in several high polymers was studied over a temperature range from 78°K to room temperature. For unvulcanized natural rubber, the absorption line narrows in the vicinity of 125°K. This is attributed to increased frequency of CH_3 group rotation. For samples vulcanized with 3, 8, and 15 percent sulfur the line width transition shifts to higher temperatures indicating increased hindrance to motion. Line width transitions occur also near the second order transition temperatures for the polymers studied, and may be ascribed in part to increased segmental motion. The absorption line for polymethyl methacrylate showed indications of structure in the temperature range from 78°K to about 140°K, similar to the theoretically predicted line shape for a rigid H_3 triangular group broadened by neighboring molecular complexes. Similar effects were observed for polyisobutylene in the same temperature range. A silicone rubber exhibited a line width transition near 125°K, but the absorption line showed no structure and remained narrow down to liquid nitrogen temperatures. Second moments of the absorption lines, plotted as a function of temperature, show similar behaviors for the polymers investigated. Activation energies for the assumed motions at the line width transitions can be obtained from the line width temperature curves.

* Supported in part by the Office of Naval Research.

Friday Afternoon at 2:00

Phoenix Room

(E. R. Fitzgerald presiding)

Invited Papers of DHPP

N1. Frictional Properties of Teflon. D. G. Flom, *General Electric.* (30 min.)
N2. Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading. H. F. Schiefer, *National Bureau of Standards.* (20 min.)
N3. Strain Propagation in Nylon Yarns Loaded Transversely at High Speeds. F. A. Odell, *Chemical Corps Medical Laboratories.* (20 min.)

Contributed Papers in High-Polymer Physics

N4. Extension of the Hertz Theory of Impact to the Viscoelastic Case. Yoh-Han Pao, *DuPont.*—The problem considered is that of two bodies coming into normal contact over smooth curved surfaces. The initial relative velocity and the total kinetic energy involved is low. Contact is, however, confined to such small volumes of the objects involved that very high concentrations of energies are obtained at those places. The rates of application of stress are correspondingly high. The Hertz solution to this type of problem provides a useful approximation in the case of elastic objects. In the present treatment either one or both of the impinging bodies may be of viscoelastic material. The Laplace transform method is used to obtain the viscoelastic expression for the force developed between the two surfaces. This expression is then applied to the impact case. The expression can also be applied to other truly static cases, e.g., contact between gear tooth surfaces. The results are of technological interest, since it is not possible to say if a plastic is suitable for a certain category of impact applications, unless the rates of straining or stressing obtained in those applications can be estimated.

N5. Dynamic Mechanical Properties of Concentrated Cellulose Trinitrate Solutions.* D. J. Plazek and John D. Ferry, *University of Wisconsin.*—The dynamic rigidities and viscosities of solutions of a cellulose trinitrate fraction (number-average molecular weight 145 000) in isophorone have been measured by the wave propagation and single transducer methods over ranges of concentration from 3.7 to 18.1 percent,

of temperature from 0° to 60°C, and of frequency from 200 to 3200 cps. When reduced to a reference state of unit viscosity and concentration, using steady flow viscosity values obtained from falling ball measurements, these data provide single composite curves for dynamic rigidity and viscosity over a range of reduced frequency of 4 to 5 powers of ten. The distribution function of relaxation times derived therefrom is a plateau with a height of about $10^{6.3}$ dyn/cm². Concentrated solutions of other cellulose derivatives (acetate, tributyrate) exhibit similar plateaus in the relaxation distribution function, with heights ranging from $10^{6.1}$ to $10^{6.4}$ dyn/cm². For vinyl polymers of comparable molecular weight, however, there is no flat plateau, the minimum (negative) slope being about 0.15 on a double logarithmic scale.

* Supported by the Allegany Ballistics Laboratory.

N6. Temperature Dependence of Relaxation Mechanisms in Amorphous Polymers and Other Glass-Forming Liquids.* MALCOLM L. WILLIAMS, ROBERT F. LANDEL, AND JOHN D. FERRY, *University of Wisconsin.*—The ratio a_T of any mechanical or electrical relaxation time at temperature T to its value at a reference temperature T_s can be expressed, after suitable choice of T_s, by $\log a_T = -8.86\ (T-T_s)/(101.6+T-T_s)$. Over a T range of $T_s \pm 50°$, this applies to a wide variety of polymers, polymer solutions, organic glass-forming liquids, and inorganic glasses. As chosen, T_s lies about 50° above the glass transition temperature T_g. An alternative (but in practice less accurate) form can be written with T_g as the reference temperature. Comparison with a simplification of Doolittle's free volume equation for temperature dependence of viscosity shows that the above empirical constants specify the increase in thermal expansion coefficient at T_g as 4.8×10^{-4} deg^{-1} (in agreement with experiment) and the fractional free volume at T_g as 0.025 (a reasonable value).

* Supported by Picatinny Arsenal and Allegany Ballistics Laboratory.

N7. The Dynamic Properties of Glucose Glass. W. PHILIPPOFF AND J. BRODNYAN, *Franklin Institute.*—The dynamic properties of polymers and polymer solutions have recently been extensively covered both experimentally and theoretically. It was thought interesting to investigate an organic glass of molecules of well-known size excluding any possible polymerization. From the investigation of Parks it is known that glucose glass can be made with a range in viscosity at moderately elevated temperatures. Such a glass was investigated in the vibration tester of the Franklin Institute in the range of temperatures from 55° to 85°C. It was found that glucose glass *has* an elasticity. The properties can be described by a Maxwell body with an additional finite viscosity. The method of reduced variables can be applied to the results. This proves that viscoelastic behavior can be obtained with nonpolymeric systems of small molecular weight.

N8. The Viscosity-Molecular Weight Relationship for Long Chain Polymers in Bulk or in Concentrated Solution. T. G. FOX AND S. LOSHAEK, *Rohm and Haas Company.*—Evidence is given showing that the relationship, $\log\eta = 3.4\log Z + K$, represents an empirical law of flow which holds generally for long flexible chain molecules in bulk or in solution, provided the chains are sufficiently long to form a network structure through chain entanglements. Here η is the viscosity, Z is the number of atoms in the chain, and K is a constant which is dependent on the polymer type and on the temperature. All of the available data which cover wide molecular weight ranges for linear (and branched) molecules in bulk or in solution, including results on polyesters, polyamides, polystyrene, polyisobutylene, polydimethyl siloxane, and polymethyl methacrylate, support this conclusion. For chains too short to form such an entangled network, the dependence of η on Z is less severe but more complex. These results are in semi-quantitative agreement with the recent theory of F. Bueche.

FRIDAY AFTERNOON AT 2:00

Calvert Room

(R. J. MAURER presiding)

DSSP Symposium on the Properties of Silver Halides

P1. Research on the Silver Halides. J. W. MITCHELL, *University of Bristol.* (40 min.)

P2. Some Recent Studies of the Light Absorption Photoconductivity and Photolysis of Silver Halide Crystals. G. LUCKEY, *Eastman Kodak Company.* (30 min.)

P3. Properties of Electrons and Holes in Silver Chloride. F. C. BROWN, *Reed College.* (30 min.)

P4. The Decay Times of Luminescence and Photoconductivity in Silver Chloride. W. S. SACK, *Cornell University.* (30 min.)

P5. Nuclear Magnetic Resonance Studies of Imperfect Ionic Crystals. F. REIF, *University of Chicago.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Founders' Room

(R. T. Cox presiding)

Photoconductivity; Color Centers; Optical and General Physics

Q1. Localized Photoconductivity in PbS Films.* DAVID DUTTON, *University of Rochester.*—The degree of localization of the effect of illumination in photoconducting layers such as PbS can be tested by applying a long narrow beam oriented first perpendicularly to, then parallel to the applied electric field.[1] If photoconductivity is not localized, for example if the

diffusion distance of minority carriers in fields of several volts/cm is comparable to the length of the film, S, the ratio of the fractional changes in over-all film resistance produced by the respective beam orientations, is unity; if the photoeffect is confined to the illuminated region, $S \sim (1-\Delta\rho/\rho)$ where $\Delta\rho/\rho$ is the fractional resistance change in the illuminated part. A value $S \sim 1$ has been reported.[1] The test has been applied to some commercially made, chemically deposited films of PbS currently being investigated by small-spot scanning methods[2]; in these films, values of $S<1$ occur, and both the lower of over-all resistance and the observed values of S can be accounted for by a localized-photoconductivity model. With a sufficiently narrow beam the test may give anomalous results ($S>1$) in films which have become polarized by ionic conduction.

* Supported in part by the Office of Scientific Research, U. S. Air Force.
[1] H. Müser, Z. Physikal. Chemie **198**, 52 (1951). I am indebted to Dr. E. S. Rittner for calling this experiment to my attention.
[2] D. Dutton, Proc. Atlantic City Photoconductivity Conference (to be published).

Q2. Photoconductivity in Potassium Iodide.* NICOLAS INCHAUSPÉ, *University of Illinois.*—Photoconductivity in potassium iodide at the temperature of liquid nitrogen has been investigated with crystals containing additive F-centers and radiation in the photon energy range from 1.9 ev to 5.8 ev. The maximum of the F-center absorption occurs at the lower limit of this photon energy range and the upper limit marks the maximum of the first (exciton) peak of the fundamental optical absorption. The concentration of F-centers was varied from 10^{14} cm^{-3} to 10^{17} cm^{-3}. The number of quanta incident per second upon the crystal was about 10^{11} per second. The observed photocurrents were less than 10^{-15} amperes in crystals which had not been additively colored. When the crystals were prepared in such a low-vapor pressure of K as to contain less than 10^{16} F-centers cm^{-3}, photocurrents became observable at 3 ev and increased to a broad maximum at 5.1 ev. For F-centers concentrations between 10^{16} and 10^{17} cm-3, additional maxima were observed at 1.9 ev and 5.51 ev where the F- and β-bands occur. The photocurrents decreased rapidly as the photon energy was increased beyond 5.51 ev.

* Partially supported by the Office of Scientific Research.

Q3. Impurity Induced Color Centers in Fused Silica. ALVIN J. COHEN, *Mellon Institute.*—Recently several workers[1-3] have associated the three color centers in fused silica having absorption maxima near 220, 300, and 540 mμ with the SiO_3 network alone and not with chemical impurities that are present. In this laboratory experiments on Heraeus Homogenized Ultrasil and Amersil grades of fused silica indicate that the color centers at 300 and 540 mμ are due to the impurity content and are related to an absorption peak at 242 mμ induced by reducing conditions between 1000 and 1400°C. These two color centers cannot be produced in Corning purified fused silica under comparable conditions of heating and x-ray treatment. A color center at 214 mμ is developed in the Corning silica, and a new center appears in certain specimens in the region of 260 mμ. The color centers in these fused silicas are compared to certain color centers found in amethyst quartz, in complex glasses colored by solarization, and in colored CaF_2. The possible impurities responsible for these color centers will be discussed.

[1] R. Yokota, J. Phys. Soc. (Japan) **7**, 316 (1952).
[2] G. Mayer and J. Gueron, J. chim. phys. **49**, 204 (1952).
[3] F. S. Dainton and J. Rowbottom, Trans. Faraday Soc. **50**, 480 (1954).

Q4. Energy Requirement for F-Center Formation. R. S. ALGER and R. D. JORDAN, *U. S. Naval Radiological Defense Laboratory.*—The effects of crystal material and lattice defects on the distribution and storage of energy absorbed from 2 Mev cathode rays and deuterons were studied through quantitative measurements of the energy required for F-center formation in pure and mixed alkali-halide crystals. These measurements were compare to previous work with Co^{60} gamma rays. The effects of crystal material were examined with a series of pure crystals containing a common alkali metal, i.e., KCl, KBr, and KI, and with mixed crystals containing various proportions of KCl and KBr. The highest coloring efficiencies were observed in crystals sensitized by the addition of the hydride, i.e., U-centers, which are converted into F-centers by the ionizing radiation. Typical energies for the U- to F-transition in sensitized KBr are 26, 30, and 80 to 100 electron volts for excitation with Co^{60} gamma rays, 1-Mev electrons, and 2-Mev deuterons, respectively. Owing to the high specific ionization of the deuterons, all of the F-centers were formed in a layer 0.013-cm thick as compared to 0.1 cm for 1-Mev electrons. The crystals have already begun to saturate by the time that detectable color-center concentration occurs with the deuterons. The conversion energy with deuterons was also very highly sensitive to the crystal condition, and the 80 to 100 electron-volt region covers the lowest energies found.

Q5. Susceptibility and Entropy of F-centers.* J. G. DAUNT AND J. KORRINGA, *Ohio State University.*—The entropy S and the paramagnetic susceptibility χ of F-centers in alkali halides have been computed using the model of Kip, Kittel, Levy, and Portis.[1] With the hyperfine coupling between the F-center electron and the six equivalent nearest alkali nuclei as the only interaction, the eigenvalues of the energy of the center in a weak magnetic field were calculated up to second order in H. The sum of states then yields an expression for S and χ as function of a reduced temperature $T^* = kT/E_e$, where E_e is twice the hyperfine coupling constant. The calculations have been limited to nuclei with spin 3/2. The influence of the hfs on χ amounts to 7.5 percent for $T^* = 10$, corresponding to $T \approx 0.01$°K for Li^6 up to $T \approx 0.4$°K for Cs^{133}. In a magnetic cooling experiment starting in a strong magnetic field at $T_i = 1$°K at most the electronic entropy R ln2 can be removed, leading to a final temperature $T_f^* \approx 3$.

* Assisted in part by a contract between the Air Research and Development Command and the Ohio State University Research Foundation.
[1] Phys. Rev. **9**, 1066 (1953).

Q6. The Emission Spectra of Some Polyatomic Molecules. G. W. ROBINSON, *The Johns Hopkins University.*—Low-excitation conditions are produced in a high-frequency electrodeless discharge operated at the highest possible pressures. For substances with low volatility, high pressures may be attained by the addition into the discharge of a spectroscopically inert material having a high volatility. Any impurities which are formed may be effectively removed by employing an extremely rapid flow rate. In this way secondary excitation of products of decompositon will not take place and the emission will be quite pure. Emission intensities are about 10^3 times higher than those obtained by ordinary fluorescence techniques. Because of the increased intensity it will be possible to study these spectra at a high resolution. Some of the molecules which have been studied are acetaldehyde, acetone, benzaldehyde, acetophenone, biacetyl, and naphthalene.

Q7. Vibration-Rotation Line Intensities in HCl and DCl.* R. HERMAN, G. E. MOORE, S. SILVERMAN, AND R. F. WALLIS, *Applied Physics Laboratory, The Johns Hopkins University.*—Integrated line intensities have been measured in absorption in the 1–0 and 2–1 bands of HCl and 1–0 band of DCl. The grating spectrographs used in this investigation had resolutions of ~0.25 to 0.50 cm^{-1} permitting intensity measurements to be made on individual isotopic lines of H^1Cl^{35}, H^1Cl^{37}, H^2Cl^{35}, and H^2Cl^{37}. A wide range of optical densities was employed, varying both pressure and path length at various

temperatures up to ~1050°C. A comparison of experimental line intensities with a theory which takes into account the vibration-rotation interaction,[1] yields the ratio, θ, of the permanent dipole moment, M_0, to the product of effective charge and equilibrium internuclear distance, $M_1 r_e$. We find for HCl and DCl that $\theta = 1.19$ and 1.05, respectively, with probable errors of ~0.05. This indicates that for small vibrations these molecules behave essentially as point charges. Absolute-integrated intensities have been obtained for a number of bands. The interdependence of the above measurements with equivalent line widths and line shapes is discussed in the following abstract.

* This work was supported by the Bureau of Ordnance and the Office of Naval Research, Department of the Navy.
[1] R. Herman and R. F. Wallis, J. Chem. Phys. (to be published).

Q8. Collision Line Widths and Shapes in the Vibration-Rotation Bands of HCl.* W. S. BENEDICT, *The Johns Hopkins University*, AND G. E. MOORE AND S. SILVERMAN, *Applied Physics Laboratory*.—Previous work[1,2] has shown that the collision line width of HCl vibration-rotation lines varies markedly with the rotational quantum number, and that the absorption at frequencies greater than several cm^{-1} from the resonance is greater than required by the Lorentz shape. By making measurements over wide ranges of optical density, pressure, and temperature as reported in the preceding abstract, it is possible to investigate these effects more closely. At our highest optical densities there was nearly complete absorption at the center of the 1–0 band. The absorption coefficient near the band origin is over three times as large as predicted from the Lorentz shape and the widths obtained at lower densities. The non-Lorentzian deviations appear to be nearly symmetrical about each line and to be greatest for the lines of lowest J. The line widths observed for all J-values in HCl and DCl are greater at all temperatures than those calculated for resonating dipoles and show the importance of nonresonant dipole-dipole, dipole-quadrupole, and possibly other higher-order interactions.

* This work was supported in part by the Bureau of Ordnance and the Office of Naval Research, Department of the Navy and in part by the U. S. Air Force, Cambridge Research Center.
[1] E. Lindholm, Z. Physik **109**, 223 (1938).
[2] W. S. Benedict and S. Silverman, Phys. Rev. **94**, 752 (1954).

Q9. The Microwave Spectrum of $N^{15}O^{16}$. J. J. GALLAGHER, W. C. KING, AND C. M. JOHNSON, *The Johns Hopkins University*.—The first two rotational transitions $J = 1/2 \rightarrow 3/2$ and $J = 3/2 \rightarrow 5/2$, of $N^{15}O^{16}$ in the $^2\pi_{\frac{1}{2}}$ electronic ground state have been measured in the one- to two-millimeter wavelength region. The results are in good agreement with calculations based upon the data previously obtained for $N^{14}O^{16}$. Since the spin of N^{15} is 1/2, there is no quadrupole interaction and the hyperfine structure consists of magnetic effects only. All six lines of the $J = 1/2 \rightarrow 3/2$ transition at an unperturbed frequency of 145 133.74 Mc/sec have been measured to an absolute accuracy of ±0.25 Mc/sec, and four of the six lines in the $J = 3/2 \rightarrow 5/2$ transition at 241 888.84 Mc/sec have been measured to an accuracy of ±0.50 Mc/sec. If the molecule is assumed to be an intermediate coupling case, slightly removed from Hund's case (a) by interactions with neighboring states, the parameters describing the Λ-type doubling are calculated to be $4\Sigma_s[(-1)^s/\nu(\pi,\Sigma)]\langle\pi|AL_y|\Sigma\rangle\langle\Sigma|BL_y|\pi\rangle = 170.44$ Mc/sec and $8\Sigma_s[(-1)^s/\nu(\pi,\Sigma)]|\langle\pi|BL_y|\Sigma\rangle|^2 = 1.49$ Mc/sec. The hyperfine structure is accounted for by the theory of Frosch and Foley, yielding the hfs constants $D = -131.90$ Mc/sec and $d = -157.98$ Mc/sec. Small hfs corrections resulting from the mixing of states are also considered. The hyperfine structure measurements yield excellent confirmation of previous nuclear magnetic moment measurements of N^{15} in both magnitude and sign. The rotational constants obtained for $N^{14}O^{16}$ are $B_0 = 49\,043.86$ Mc/sec and $D_0 = 0.14$ Mc/sec.

Q10. The Ideal Gas Thermodynamic Properties of the Isotopic Hydrides of a Group of Diatomic Free Radicals. LESTER HAAR, *National Bureau of Standards*.—Procedures were employed to obtain the partition functions for the diatomic hydrides, deuterides and tritides of the free radicals of the elements of group IVA and VA of the periodic table. The calculations include the special low-temperature electron spin interaction effects arising with these molecules.[1] In addition to these effects the partition functions include corrections for rotation-vibration coupling, vibrational anharmonicity, centrifugal stretching and nonclassical rotation. Tables of thermodynamic properties from 50°–5000°K have been calculated on the NBS digital computer—SEAC for the isotopic hydrides of the elements C, Si, Sn, Pb, N, and P. The molecular data for the hydrides were used to compute the data for the deuterides (when not available), and for the tritides.

[1] Lester Haar and A. S. Friedman, J. Chem. Phys. (to be published).

Q11. Cine-Microscopy of Sparks, Exploding Wires, and Fracture at Framing Rates $>10^6$/Second. L. ZERNOW AND G. HAUVER, *Aberdeen Proving Ground*.—An ultra-high-speed framing camera[1] similar to the one developed at Los Alamos and described by Brixner[2] has been adapted for use with a magnifying objective. Dynamic microscopic details of electrode behavior in sparks, disintegration of exploding wires, and crack formation in glass shattered by explosives have been observed. Previous studies of such phenomena[3] have used static-microscopic observation. However, with the exception of Froome's micro studies of cathode spots on liquid metals,[4] dynamic studies appear to have always been carried out macroscopically.[5–7] High-speed photomicrographic sequences will be shown to illustrate the additional microscopic detail obtainable. Shorter exposure times (~10^{-8} seconds) and the very high framing rates ($\gg 10^6$/second) will be recognized as essentials for extracting the maximum microscopic detail.

[1] Available from Beckman and Whitley, Inc., San Carlos, California.
[2] B. Brixner, J. Soc. Motion Picture Television Engrs. **59**, 503 (1952).
[3] Kies, Sullivan, and Irwin, J. Appl. Phys. **21**, 716 (1950).
[4] K. D. Froome, Proc. Phys. Soc. **62B**, 805 (1949); **63B**, 377 (1950).
[5] W. Göing, Naturwiss. **37** (No. 24), 558 (1950).
[6] Allen, Hendricks, Mayfield, and Miller, Rev. Sci. Instr. **24**, 1068 (1953).
[7] D. G. Christie, Trans. Soc. Glass. Tech. **36**, 74 (1952).

Q12. Metallic Deposits and Shock Waves Due to Electrically "Exploded" Wires. WILLI M. CONN.—Experiments are described for obtaining a profile through the metallic vapor surrounding an "exploding" wire. It was earlier shown that uniform-metallic deposits may be formed on glass, etc. by this method at pressures varying for different metals. It was now found that the cylinder or shell of metallic vapor surrounding the wire is hollow and closed at both ends. The shell is formed prior to the violent "explosion." A cylindrical shock wave produced inside the hollow cylinder by the "exploding" wire will be partly reflected from the inside of the shell, and partly propagated through the metallic vapor. The cylindrical compression wave formed by reflection will cause very high pressure and temperature along the axis of the shell, *cf.* the emission of continuous spectra due to very high-temperature and free-free transitions, the high energy emitted by exploding wires and the "falling out" of ionizing constituents from the cloud of explosion products after experiments at atmospheric pressure. Example of size of shell (Ag No. 34 ga, 60 mm long, 5 mm gap, 25 mm Hg pressure): 8.2 mm inside, 23.8 mm outside diameter; 55 mm inside, 65 mm outside length. Means for direct observation of the inside of the shell and its connection to the outside will be discussed.

FRIDAY AFTERNOON AT 2:00

Caswell Room

(R. SMOLUCHOWSKI presiding)

Metals, I

R1. Valence Wave Functions for the $3d^74s$ and $3d^8$ Configurations of Atomic Iron.* FRANK STERN, *U. S. Naval Ordnance Laboratory.*—Self-consistent field wave functions without exchange have been calculated for $3d$ and $4s$ electrons in the $3d^74s$ and $3d^8$ configurations of atomic iron, using the core potentials found by Manning and Goldberg[1] for the $3d^64s^2$ configuration. The fractional charge of a $3d$ electron outside a sphere of radius 2.66 Bohr radii is 0.05, 0.10, and 0.15, respectively, for the $3d^64s^2$, $3d^74s$, and $3d^8$ configurations. Thus any property which depends on the amount of charge far from the nucleus, for example the width of the $3d$ band of metallic iron in a tight binding approximation, will be considerably different in the three cases. The eigenvalues found in solving the Schrödinger equation are corrected for the difference between output and input potentials, and energies of the three configurations (neglecting all Slater integrals except F^0) are found. Preliminary estimates are −37.03, −36.68, and −36.32 Rydbergs, respectively, for the energies of the $3d^64s^2$, $3d^74s$ and $3d^8$ configurations relative to a state in which the valence electrons are widely separated from the core.

* This work was begun at Princeton University.
[1] M. F. Manning and L. Goldberg, Phys. Rev. **53**, 662 (1938).

R2. A Quantum-Mechanical Calculation of Inter-Atomic Force Constants in Copper. HARRISON C. WHITE, *M.I.T.*—Feynman's Theorem[1] tells us that the force on a nucleus resulting from the displacement of one other nucleus can be reduced to the coulomb force produced by the change in total charge density. We assume each ion-core moves rigidly and shows the central-force repulsion used by K. Fuchs for elastic constants. Hence determination of the localized change in the $4s$ band conduction electron charge density $\Delta\rho$ is our primary problem. A conventional scattering theory approach is inappropriate; instead the Slater-Koster perturbation theory formulation in Wannier functions[2] has been applied to the lower half of the discrete eigenspectrum of small, fcc lattices. An explicit expression is obtained for $\Delta\rho$ using plane waves as unperturbed wave functions, and the perturbation matrix components between first neighbors as a single disposable parameter limited by self-consistency. $\Delta\rho$ has been evaluated for lattices of two shapes and seven sizes up to sixteen atomic planes in width to verify convergence, and is compared with a semiempirical multipole expansion. The resulting atomic force constants are in general agreement with those inferred from thermal diffuse scattering of x-rays in recent work, and contradict any central force model.

[1] R. P. Feynman, Phys. Rev. **56**, 340 (1939).
[2] G. F. Koster and J. C. Slater, Phys. Rev. **95**, 1167 (1954).

R3. Work Function Difference of Gold and Gold Oxide from Contact Potentials with Respect to Germanium and Platinum.[1] PAUL MILLER, *University of Pennsylvania.*[2]—An apparatus has been developed for 25 cpd observations per second by extension of the Kelvin method to rotational geometry. A sample is mounted on a post on a disk rotating at 1500 rpm past the reference. A sample is seldom over the reference, thus being available to various devices (e.g., heater, radiation pyrometer). Samples may be mounted on different arcs of the disk and rapidly intercompared. By this means the work function difference between massive polycrystalline gold oxidized in air and gold reduced in hydrogen was measured as 1.06±0.08 volts, agreeing with a photoelectric determination by Weiss,[3] whose preparation methods were followed. A germanium sample, which proved insensitive to hydrogen, enabled following of work function changes of the platinum nominal reference. As another possible use of the apparatus, at 10^{-6} mm, a surface prepared bare at a given time can be measured 25 times before formation of a monolayer from the ambient, an ultra-high vacuum being unnecessary.

[1] Supported by the Office of Naval Research.
[2] Now at Bell Telephone Laboratories.
[3] Private communication from P. Weiss, Socony-Vacuum Company.

R4. Thermoelectric Power and Resistivity of Dilute Alloys of Mn, Pd, and Pt in Cu, Ag, and Au.* F. A. OTTER, JR., *Franklin Institute Laboratories.*—We have measured the thermoelectric power and resistivity of dilute alloys of Cu-Mn, Ag-Mn, Au-Mn, Cu-Pd, Ag-Pd, Au-Pd, Cu-Pt, Ag-Pt, and Au-Pt from −195°C to +500°C. Norbury[1] has reported thermoelectric data for Cu-Mn alloys, and Geibel[2] has measured the thermal emf of Au-Pd and Ag-Pt against Pt from 0°C to 1000°C. Geibel's most dilute alloys contained 10 At percent Pd, and our data for pure Ag and Au disagree with his. We chose the alloys mentioned because of the good solubilities of Mn, Pd, and Pt and because of the similar properties of Au, Ag, and Cu. We found that the thermopowers of "noble" metal alloys of Pt and Pd are negative relative to the pure solvent metals as is found for most solutes. Noble metal alloys of Mn, on the other hand, are thermoelectrically positive relative to the pure solvent metal above certain temperatures. The transition from negative to positive relative thermopower occurs at about room temperature for Cu-Mn, about −170°C for Ag-Mn, and about +200°C for Au-Mn.

* This work was supported by Signal Corps Engineering Laboratory.
[1] A. L. Norbury, Phil. Mag. **2**, 1188 (1928).
[2] W. Geibel, Z. anorg. Chem. **69**, 38 (1911); **70**, 240 (1911).

R5. Anisotropic Electronic Stress and Magnesium Alloys. PAUL M. MARCUS, *Carnegie Institute of Technology.*—Calculations have been made of the anisotropic electronic stress due to Brillouin zone boundary effects on the Fermi energy as electron concentration varies. The form of the energy throughout **k** space is assumed given by free electron perturbation theory with only one Fourier component of the lattice potential as the perturbation; the energy and energy gap values are taken, however, from Trlifaj's calculations on magnesium. Because of the cylindrical symmetry the calculations may easily be carried out exactly. The resulting stress along the hexagonal axis varies with electron concentration in agreement with Goodenough's rough calculation, giving first, rising tension as the Fermi surface approaches the zone face, then falling tension after contact is made. The increased tension due to overlap agrees with Jones's simple theory, although now such effects as distortion of the energy surfaces under strain, spillover of overlap electrons under stain, and anisotropy of the overlap band are included. Application to lattice spacing changes of selected magnesium alloys, using Jones's assumption that alloying simply adds electrons to the conduction band, shows the magnitude of the overlap stress is reasonable, but the stress does not start as abruptly nor continue rising as linearly with increasing concentration as observed.

R6. Brillouin Zone Studies of Alloys IV Additional Hall Data of Magnesium Alloys. A. I. SCHINDLER AND E. I.

SALKOVITZ, *Naval Research Laboratory.*—It has been suggested by Salkovitz and Schindler that the Brillouin Zone overlap in dilute magnesium alloys can be studied by observing various electrical properties (e.g., transport phenomena) as a function of alloying additions. Measurements of $d\rho/dt$, where ρ is the electrical resistivity, show a break at an electron concentration of approximately 2.013 electrons per atom. Preliminary Hall measurements on alloys of magnesium containing small amounts of aluminum showed a similar overlap effect at roughly the same concentration. More complete Hall measurements have been made on dilute binary magnesium alloys containing either aluminum, indium, or tin. The data on the aluminum additions now show the break more conclusively than previously. The absolute magnitude of the Hall constant decreases nearly linearly with aluminum content up to a concentration of about 1.3 atomic percent (e.g., electron concentration of 2.013 electrons per atom). Further additions cause the Hall constant to increase slowly. A break is also observed in the curve for the indium-magnesium alloys. Beyond this break, the Hall constant increases rapidly with increasing indium content. Hall constant variation due to tin additions differ from those due to the other alloy additions, studied. For small tin concentrations the Hall constant rises and then decreases as further tin additions are made.

R7. Resistivity of Dilute Magnesium Alloys. E. I. SALKOVITZ AND A. I. SCHINDLER, *U. S. Naval Research Laboratory.*—Linde has shown that for the monovalent metals, the increase in resistivity due to small alloying additions is proportional to the square of the difference in valence of the two elements concerned. To determine whether the rule is applicable to divalent metals resistivity measurements were made of a series of dilute binary alloys of magnesium containing either lithium, silver, cadmium, aluminum, indium, thallium, tin, or lead. Silver, lithium and cadmium each produced an increase of about 0.7 to 0.9×10^{-6} ohm cm per atomic percent addition. Aluminum and indium caused an increase of from 1.9 to 2.1×10^{-6} ohm cm per atomic percent, whereas thallium, also a 3rd column element, produced a change of 3.1×10^{-6} ohm cm per atomic percent. These values were relatively constant to nearly the respective solubility limits. Additions of quadravalent tin or lead produced a different effect, however. An addition of 0.05 atomic percent of tin caused a change of 7.1×10^{-6} ohm cm per atomic percent, but this incremental change decreased rapidly with increasing tin content to 3.5×10^{-6} ohm cm per atomic percent at 2.0 percent tin. Lead produced similar effects. The data show that although Linde's Rule in its simple form is not valid for magnesium alloys, the increase in resistivity is nevertheless related to the valence of the alloying addition.

R8. On the Resistivity Due to Point Imperfections in Copper.* F. J. BLATT, M. C. HUSE, AND R. A. RUBENSTEIN,† *University of Illinois.*—Recently, calculations of resistivity due to lattice imperfections in copper were reported.[1] To determine the reliability of these calculations we have used the same procedure to determine the resistivity due to small concentrations of gallium, germanium, and arsenic in copper. The scattering potentials representing the impurities were derived from the Hartree potentials of the free ions, and the cross sections were calculated by the partial wave method. The Friedel sum rule served as a guide to suitable screening charge distributions. The calculated resistivities, although of correct magnitude, consistently exceeded experimental values, indicating that previous results for vacancies and interstitials are high by a factor of about 2. The integrations of the radial wave equation for various potentials were performed by the ILLIAC using a program originally designed to facilitate self-consistent field calculations.[2] This program, which is equally suited to eigenvalue problems (bound states) as to scattering calculations, will also be discussed.

* Supported in part by the Office of Naval Research.
† Now at Shell Development Company.
[1] F. J. Blatt, Bull. Am. Phys. Soc. **29**, No. 7, 30 (1954).
[2] R. A. Rubenstein, Ph.D. thesis, University of Illinois (1954).

R9. Elastic Constants of Ag and Ag Alloys.* ROGER BACON† AND CHARLES S. SMITH, *Case Institute of Technology.*—The elastic constants of single crystals of silver and of dilute silver alloys have been measured by the ultrasonic pulse echo method. The values for pure silver in units of 10^{12} dyne cm^{-2} are: shear constant $(C_{11}-C_{12})/2$, 0.1528; shear constant C_{44}, 0.461; adiabatic bulk modulus, 1.036. First measurements on a series of dilute alloys of silver have been completed for a crystal containing 8 atom percent indium. The elastic constants show a decrease upon alloying to an extent which is in qualitative agreement with results previously reported for alloys of copper. The fractional decrease in $(C_{11}-C_{12})/2$ is much larger than that of C_{44} suggesting a decrease of the short range forces and an increase in the long range electrostatic forces upon alloying.

* This work was supported by the Office of Naval Research.
† National Carbon Fellow.
[1] J. R. Neighbours and C. S. Smith, Acta Met. **2**, 591 (1954).

R10. Elastic Constants of Fe-Si Alloys.* CHARLES S. SMITH AND W. B. DANIELS, *Case Institute of Technology.*—The elastic constants of body centered cubic Fe-Si single crystals of composition 4.9, 6.0 and 10.7 atom percent silicon have been determined by the ultrasonic pulse echo method. An increase of silicon content in this composition range has the following effects on the fundamental elastic constants: The bulk modulus B shows no significant change; the shear constant C_{44} decreases by two percent; the shear constant $(C_{11}-C_{12})/2$ shows a large decrease of 15 percent. The constant $(C_{11}-C_{12})/2$ extrapolates back very well to the value for pure iron, of which all four determinations in the literature are in excellent agreement. The constants B and C_{44} do not extrapolate well but neither do their pure iron values agree well. These results then are formally very similar to those previously reported for a wide variety of face centered cubic copper and silver alloys. Their interpretation is hampered by the lack of a theory for the elastic constants of iron. The very different behavior of the two shear constants upon alloying suggests however that short range interactions alone cannot account for the shear constants of iron. The large decrease in $(C_{11}-C_{12})/2$ may account for the increased stability of the body centered phase when silicon is added in solid solution.

* This work was supported by the Office of Naval Research.

R11. Temperature Dependence of Internal Friction in Copper.* D. N. BESHERS AND J. S. KOEHLER, *University of Illinois.*—The internal friction and effective Young's modulus of copper single crystals, some 99.999 percent pure and others with small amounts of gold, have been measured at elevated temperatures. The decrement increases very rapidly as a function of temperature. Above ~350°C, activation energies may be deduced from the temperature dependence. In pure Cu, two apparent activation energies are involved, below and above ~550°C, for which preliminary values are 23.6 and 16.2 kcal/mole, respectively. These are observed at a maximum strain amplitude (in longitudinal resonance) of 4×10^{-6}. Gold appears to affect the second energy, reducing it to 12 kcal/mole. The highest temperatures reached tentatively indicate a peak about 1000°K, consistent with Wert and Marx's systematics[1] for an activation energy of ~46 kcal/mole.

* Supported by Office of Naval Research.
[1] C. Wert and J. Marx, Acta Met. **1**, 113 (1953).

R12. Precipitation in Small Spheres of Lead-Tin Alloy. W. DESORBO AND D. TURNBULL, *General Electric Research Laboratory.*—Studies[1] on the kinetic behavior of bulk polycrystalline α-lead tin indicate that the precipitation of tin (β) is accomplished by nucleation and growth of cells consisting of tin lamellae interspersed in depleted solid solution. It has been suggested[2] that both the nucleation and growth of precipitate is catalyzed by structural irregularities in the solid solution and that the rate of cellular precipitation should be greatly depressed in structurally perfect crystals. The precipitation reaction in very small (30–40 micron diameter) crystal spheres of Pb-Sn alloy, that may be free of grosser imperfections, has been followed by a calorimetric technique. In all cases the precipitation energy evolved isothermally is only 1/10 to 1/25 of the values evolved by bulk polycrystalline specimens having the same composition. The precipitation energy evolved by the spheres cold-worked and homogenized once is several orders of magnitude larger than the energy released prior to deformation. Supersaturation ratios of 10 to 20 were supported for several hours at 300°K without precipitation. The results demonstrate the decisive role of lattice imperfections in some cellular precipitation processes.

[1] D. Turnbull and H. N. Treaftis, Acta Met. (to be published).
[2] D. Turnbull, Acta Met. (to be published).

FRIDAY EVENING AT 7:00

Calvert Room

(R. T. BIRGE presiding)

Banquet of the American Physical Society

Presentation of the John Scott Award to WALTER H. BRATTAIN and JOHN BARDEEN.

After-dinner speeches by G. H. DIEKE and W. F. G. SWANN.

SATURDAY MORNING AT 9:30

Caswell Room

(HARVEY BROOKS presiding)

Metals, II

S1. Effect of Cold Work on Local Order. B. L. AVERBACH AND P. S. RUDMAN, *M.I.T.*—The local order contribution to the x-ray diffuse scattering was measured from an alloy 0.15 Au–0.85 Cu both before and after cold working by grinding. It was found that about three-fourths of the existing local order was randomized. These results are interpreted to mean that slip has occurred on about one-third of all possible (111) slip planes. This technique gives a measurement of the slip process for deformations beyond the reach of usual metallographic methods. A consequence of these results is that an energy of randomization should be included in calculations of energy storage in cold-worked alloys. The alloy 62 Au–38 Ag, where both energy storage and x-ray measurements have been made, is used as an example to calculate a probably significant energy of randomization. The effect of restoration of local order in annealing is discussed in terms of observations on hardness changes in α brass.

S2. Measurements of X-Ray Diffuse Scattering from Co-Pt Disordered Solid Solutions and of Long-Range Order for the Alloy CoPt. P. S. RUDMAN AND B. L. AVERBACH, *M.I.T.*—The x-ray diffuse scattering from a binary alloy has contributions from thermal vibrations, deviations from randomness, and disparities in atom sizes. The latter two contributions have been measured from Co-Pt powder briquets quenched from the disordered region. Short-range order of the same magnitude as in the Au-Cu system and a size effect of the same magnitude as in the Au-Ni system was found. The short-range order results are used to estimate the quasi-chemical contribution to the thermodynamic properties which, when added to a calculated strain contribution, give reasonable agreement with the observed thermodynamic data. The CoPt order-disorder transformation was studied by x-ray integrated intensity and c/a ratio measurements. A first-order transformation differing from that of its isomorph CuAu was found. The value of the Bragg-Williams long-range order parameter at the critical temperature S_c is: S_c (CoPt) $=0.775$ as compared to S_c (CuAu) $=0.983$.

S3. Correlation of Expansion Coefficient Anomaly in Quenched Cu_3Au With Properties of Ordered Cu_3Au.* JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.*—Bimolecular kinetics[1] applied to resistivity relaxation data of Burns[2] on ordered Cu_3Au gave 30 kcal for the net energy to create 6.01×10^{23} wrong pairs, each in an ordered environment, and a 9-kcal barrier preventing interchange of the neighboring atoms of each pair (righting them). If (a) quenched Cu_3Au contains a metastably high concentration of pairs wrong with respect to a site labeling making nearest neighbors of the pair right, (b) nearest neighbor interactions dominate atomic rearrangement processes, (c) short-range interactions are independent of long-range order, then anomaly in order-sensitive properties of quenched specimens should occur as a function of temperature which is (a) similar on the low-temperature side to the low side of the lambda-point anomaly, (b) in the opposite direction (e.g. decrease instead of increase), (c) characterized by linear plot of logarithm of anomalous deviation *vs* $1/T$, with activation energy 9 kcal in Cu_3Au. The expansion coefficient dip of quenched Cu_3Au observed by Nix and MacNair[3] agrees with these predictions.

* Work done partly at Columbia University.
[1] J. Rothstein, Phys. Rev. 94, 1429(A) (1954).
[2] F. Burns, Phys. Rev. 94, 1429(A) (1954).
[3] F. C. Nix and D. MacNair, Phys. Rev. 60, 320 (1941).

S4. Isothermal Anneal Study of Quenched and Cold-Worked Copper-Palladium Alloys.* A. SAWATZKY AND F. E. JAUMOT, JR., *Franklin Institute Laboratories.*—The behavior of the electrical resistivity of copper-palladium alloys in the composition range from six to thirty atom percent palladium has been studied in the course of isothermal anneals at temperatures from 250°C to 450°C. Samples quenched from 800°C and samples cold-worked to ninety percent reduction in area were used. Samples of both initial conditions exhibited an increase in resistivity followed by a rather rapid decrease. The two regions are attributed to nucleation and growth of ordered domains. The activation energy for growth of ordered domains is approximately 42 kcal/mole for samples quenched from 800°C. The nucleation process is probably not a singly activated process, but the mean activation energy in the temperature range from 325°C to 400°C is of the order of 20 kcal/mole. Samples previously cold worked appear to have a slightly lower activation energy for growth of the ordered domains. These data, combined with other rather meager data available on these alloys, indicate that a rather serious revision of the equilibrium diagram of Cu-Pd alloys is needed.

* This work was supported by the Office of Ordnance Research.

S5. Small-Angle Scattering of X-Rays by Surface Irregularities.* W. H. ROBINSON AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—It has been pointed out previously[1] that surface irregularities can produce strong small-angle scattering and overshadow scattering by internal defects. An early attempt to check this effect by mechanically polishing diamond failed presumably because of the too coarse polishing medium. In order to investigate this phenomenon further, thin slices of a single crystal of zinc were cut parallel to the basal plane by means of a strain-free acid cutter. The thickness of the sample was reduced down to 0.003 in. by means of etching and electrolytic polishing. The small-angle scattering measured at angles smaller than forty minutes of arc was large and independent of previous annealing history of the sample. This is in contrast to another sample obtained by cold rolling polycrystalline zinc to a similar thickness. This sample showed in the same range of angles very small scattering which upon a subsequent slight electrolytic polishing was raised about tenfold. This confirms the supposition that the surface condition of the sample plays a very important role in small-angle scattering of x-rays.

* Work supported by a contract with the U. S. Atomic Energy Commission.
[1] Y. Y. Li and R. Smoluchowski, J. Appl. Phys. (to be published).

S6. Grain Boundary Diffusion in the Al-Cu System.* C. COLEMAN AND R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—In continuation of the previous work on grain boundary diffusion, the system aluminum-copper has been chosen in order to investigate the influence of the relative size of atoms on grain boundary diffusion and in particular on the role of dislocations and of dislocation clusters. The system offers the possibility of obtaining columnar grains on both its ends. The diffusion of aluminum along the grain boundaries of copper in the common cubic direction has been studied first using a sensitive differential etching technique. In the diffusion couple the source of aluminum is a copper −7 wt percent aluminum alloy kept in contact with the columnar copper. A typical diffusion run of 170 hr at 600°C provides a very deep grain boundary penetration indicating an activation energy for the grain boundary diffusion around 10 000 cal per mole. In accord with previous results there is very little if any penetration at low-angle boundaries and the penetration increases with increasing angle of disorientation. Preliminary results of diffusion of copper in columnar aluminum have also been obtained.

* Work supported by a contract with the U. S. Atomic Energy Commission.

S7. Self-Diffusion in Zinc at Low Temperatures.* F. E. JAUMOT, JR., AND R. L. SMITH, *Franklin Institute Laboratories.*—Self-diffusion in zinc at temperatures below 200°C has been studied using both single crystal and polycrystal samples. Anomalous results were obtained for single crystal samples; the data indicating that in some samples grain boundary diffusion predominated, and in others, volume diffusion predominated. These anomalous results are attributed to low-angle lineage boundaries which are presumed to be formed of edge dislocations. The diffusion in certain polycrystal samples could be analyzed as predominately volume diffusion. When volume diffusion occurred in either single or polycrystal samples, the values for the diffusion coefficient were as much as several orders of magnitude larger than would be expected from high-temperature data.

* This work was supported by the U. S. Atomic Energy Commission.

S8. Annealing Kinetics of Lattice Defects in Evaporated Copper Films.* NED S. RASOR,† *Case Institute of Technology.*—Further results[1] have been obtained in a study of the annealing kinetics of lattice defects in vacuum deposited copper films. The electrical resistivity was used as an index of the degree of imperfection. Substrate temperature during deposition of the films ranged from −250°C to −25°C and was found to have a large effect on their annealing behavior. Annealing spectra and activation energies were obtained over the temperature range −250°C to 300°C by means of tempering and isothermal anneals. Kinetic analysis of the annealing data indicated that processes having unique activation energies do not characterize the annealing over any appreciable interval. The relation of the present work to that on irradiated and cold-worked copper is discussed. A speculation is made on the possible existence of significant quantum effects and a resulting departure from classical statistical equilibrium based on certain features of the data.

* Supported by the Office of Naval Research.
† Now at North American Aviation, Inc., Downey, California.
[1] N. S. Rasor and R. W. Hoffman, Phys. Rev. 94, 1406(A) (1954).

S9. Structure of Evaporated Copper Films on Titanium.* R. E. SCHLIER, *Brown University.*—Copper is deposited by evaporation at a rate of $(1.5\pm0.4)\times10^{15}$ atoms/cm²/min on the hexagonal (0001) face of a titanium single crystal. The crystal has been previously cleaned by outgassing *in vacuo* followed by argon ion bombardment and annealing.[1] Low-energy (less than 250 ev) electron diffraction indicates that the deposit is oriented with respect to the titanium, with the (111) copper plane parallel to the (0001) titanium plane. The hexagonal nets of copper and titanium are parallel. The lattice constant of the hexagonal net of copper is found to be 2.55 A, for all thicknesses of deposit used (0.5 to 25 monolayers). Most of the contribution to the diffraction beams is from the first 10 atomic layers of copper. Weak diffraction beams from titanium are still present after a deposit of 25 ± 7 monolayers. These observations suggest that the deposit is composed of oriented crystallites, with some of the substrate being relatively uncovered. Annealing the deposit at approximately 350°C destroys most of the orientation without removing the film.

* Assisted by Office of Ordnance Research, U. S. Army.
[1] Schlier, Farnsworth, and George, Bull. Am. Phys. Soc. 29, No. 7, 35 (1954).

S10. Mechanical Twinning in Copper. T. H. BLEWITT, J. K. REDMAN, F. A. SHERRILL, AND R. R. COLTMAN, *Oak Ridge National Laboratory.*—Studies of the mechanical properties of copper single crystals at 4.2°K showed that deformation occurs by the usual slip process at this temperature so long as the sample has not excessively work hardened. At high flow stresses (12 kg/mm² to 20 kg/mm², depending on the

orientation), a change in the mode of deformation was apparent as discontinuous flow occurs. Considerable indirect evidence suggested the possibility that mechanical winning was occurring in this second mode of deformation.[1] Although it is accepted that hexagonal metals can be deformed by mechanical twinning, experiments purporting to show deformation twinning in the face-centered cubic metals have been regarded with skepticism. Despite the fact that these earlier studies were made at room temperature, the suggestion of twinning at 4.2°K was also received with skepticism. Recent orientation determinations of the twin-like lamella utilizing a two-circle x-ray goniometer to study the {222}, {400}, {331}, {220}, {420} reflections make it possible to demonstrate unambiguously that copper forms mechanical twins at 4.2°K. The composition plane is the {111} with a [112] twinning directions. Photographs showing the growth of the twin crystal from lamella about 1/16-in. thick to approximately 4-in. thick will be shown.

[1] Blewitt, Coltman, and Redman, Proc. Bristol Conference on Imperfections in Solids, 1954 (to be published).

S11. Satellites in the Soft X-Ray Spectrum of Zr.* J. KORRINGA, *Ohio State University.*—Measurements by Spielberg and Shaw[1] of the soft x-ray spectrum of Zr, performed with a high-resolution spectrometer, have been reported. Several lines with L_{II} as initial state, notably $L\gamma_1$ ($L_{II}\rightarrow N_{IV}$), have a structure suggesting satellites. The lines $L\beta_2$ and other lines with L_{III} as initial state are single. These facts are well in accord with the mechanism proposed by Coster and Kronig,[2] according to which such satellites are emitted after a radiationless transition $L_I\rightarrow L_{II,III}$ with simultaneous ejection of an order (M-shell) electron. For $L_I\rightarrow L_{II}$ this is energetically possible for $Z<41$, the probability decreases when the energy transfer ΔE to the ejected electron becomes large. From the identity of the two effects as a function of ΔE and from the available data for lines with L_{III} as initial level, we expect a maximum satellite intensity for $L_{II}\rightarrow$transitions near $Z=39$, and a gradual vanishing near $Z=35$.

* Supported by the U. S. Atomic Energy Commission.
[1] N. Spielberg, C. H. Shaw, and J. A. Soules, Phys. Rev. **94**, 752(A) (1954).
[2] Coster and Kronig, Physica **2**, 13 (1935).

S12. Relaxation of a Monatomic Crystal Lattice Around a Vacancy.* STEFAN MACHLUP, *University of Illinois.*—An elastic continuum approach shows that the relaxation of the lattice must be in toward the vacancy, i.e., the volume increase on formation of a vacancy is *less* than one atomic volume. The vacancy is treated as a spherical hole with surface energy (=surface tension at the melting point); spherically symmetric relaxation causes shearing strains. Minimizing the sum of surface energy and strain energy gives a linear relaxation of 6 percent for Cu, 11 percent for Na, and total energy of formation of a vacancy of 1.6 ev for Cu, 0.6 ev for Na. These results are compared with the published calculations for Cu[1] (which predict less relaxation) and with a modified Huntington-Seitz calculation for Na, with a view to their relevance to self-diffusion.[2]

* Research Supported in part by contract with U. S. Air Force.
[1] H. B. Huntington and F. Seitz, Phys. Rev. **61**, 315 (1942); H. B. Huntington, Phys. Rev. **61**, 325 (1942); G. J. Dienes, Phys. Rev. **86**, 228 (1952).
[2] Nachtrieb, Catalano, and Weil, J. Chem. Phys. **20**, 1185 (1952); D. F. Holcomb, thesis, University of Illinois, 1954.

S13. On the Mechanism of Grain Boundary Relaxation in Metals and Alloys.* A. S. NOWICK AND CHI YAO LI,† *Yale University.*—Strain relaxation experiments on wires of a Ag-Zn solid solution show that the relaxation time not only for stress-induced ordering but also for the GBR (grain boundary relaxation) may be decreased considerably by quenching from elevated temperatures. This result seems to suggest that excess vacancies trapped by quenching hasten the GBR process. One day, therefore, conclude that GBR is intimately related to volume self-diffusion, as originally suggested by Kê. Recent internal friction studies by Pearson and Rotherham (to appear in the *Journal of Metals*) show that in Cu and Ag there are two GBR peaks. The first, occurs in the pure metals with an activation energy about half that for self-diffusion. This GBR effect is destroyed by addition of about 1 percent solute and replaced by a second GBR peak for which the activation energy is equal to that for self-diffusion. A consistent explanation is that the normal GBR mechanism, which occurs in pure metals, is readily blocked by the presence of impurity atoms. Thus the only available mechanism for GBR in alloys is diffusional flow.

* Work supported by the U. S. Army, Office of Ordnance Research.
† Now at Lehigh University, Bethlehem, Pennsylvania.

SATURDAY MORNING AT 9:30

Founders' Room

(FERD WILLIAMS presiding)

Physics of Photography; Silver Halides

T1. Sequence Experiment for the Study of the Reciprocity Law Failure at Low Intensities.* J. H. ENNS, R. L. MARTIN, AND E. KATZ, *University of Michigan.*—The concept that the reciprocity law failure at low intensities results from disintegration of the latent image in its initial stages of formation has been supported experimentally by Webb and Evans[1] in their publication of the sequence exposure curves, and theoretically by Katz.[2,3] In principle the sequence experiment consists of exposing a photographic emulsion in part to high- and in part to low-intensity radiation, wherein the ratio of the two exposures and their sequence may be varied. An instrument will be described, which has recently been built in this laboratory and designed especially to record automatically sequence exposure data. An exposure is made on a 4 by 10 in. plate, each plate receiving 384−4 by 5 mm squares uniformly exposed for densitometry measurements. Provision is also made to record plate calibration data. A few preliminary curves will be shown.

* Work supported by the Air Research and Development Command.
[1] J. H. Webb and C. H. Evans, J. Opt. Soc. Am. **28**, 431 (1938).
[2] E. Katz, J. Chem. Phys. **17**, 1132 (1949).
[3] E. Katz, J. Chem. Phys. **18**, 499 (1950).

T2. Photographic "Order Principle." E. KATZ, *University of Michigan.*—Although latent image theory usually refers to the single grain, most experiments deal with an ensemble of many grains in a photographic emulsion. With respect to a given set of development conditions, the developability of each grain follows a step function during the exposure, whereas the overall developable density of the emulsion varies quasi continuously. In order to provide a most general link between

single-grain behavior and ensemble results the "order principle" has been proposed.[1] It will be shown that, much like a converging-power series, the order principle can be applied with various degrees of approximation, depending on the amount of available information concerning emulsion and development variables; its accuracy can, in principle at least, be increased indefinitely.

[1] E. Katz, J. Chem. Phys. 17, 1132 (1949).

T3. Low-Intensity Reciprocity Law Failure for Pure Ag Br Emulsions of Different Grain Size.* R. L. MARTIN, J. E. ENNS, AND E. KATZ, *University of Michigan.*—The photographic reciprocity-law failure (r.l.f.) is exhibited by plotting the logarithm of the exposure (intensity×time of exposure) which is required to produce a constant density, *vs* the logarithm of the intensity of the exposure. The negative slope of this curve indicates that a stable speck is less likely to occur and then grow to a developable speck, for low than for optimal intensity exposures. It has been shown that the slope of the r.l.f. curves for low intensities reflects the distribution of the trap depths encountered by the conduction electrons in the Ag Br grain.[1] Since the traps are located partly near the surface and partly throughout the volume of a grain, one may expect to find a dependence of the slope of the r.l.f. curve with gain size. We will present preliminary results of measurements of the dependence of low intensity r.l.f. slopes on grain size.

* Work supported by the Office of Ordnance Research.
[1] E. Katz, J. Chem. Phys. 17, 1132 (1949).

T4. Displacement of Latent Image in Photographic Emulsion Grains. J. F. HAMILTON, F. A. HAMM, AND J. W. CASTLE, *Eastman Kodak Company.*—The use of simultaneous light and voltage pulses in the study of the motion and trapping of photoelectrons in large, single crystals of silver chloride has been described by Haynes and Shockley.* A similar technique has been successfully applied to photographic silver-bromide grains. The conduction electrons are displaced from their liberation sites toward or completely to an edge of the grain by the electric field during and after the 5 μ-second light pulse. Displaced print out as well as latent-image silver will be illustrated. The present results are qualitative; however, various factors affecting the trapping of the conduction electron will be briefly discussed.

* J. R. Haynes and W. Shockley, Phys. Soc. (Bristol), Conf. Rept., p. 151 (1948); J. R. Haynes and W. Shockley, Phys. Rev. 82, 935 (1951).

T5. Optical Absorption Measurements on Silver Halide Crystals. NELSON R. NAIL, FRANK MOSER, PLINY E. GODDARD, AND FRANZ URBACH, *Eastman Kodak Company.*—Using extensive precautions to insure high purity, large silver-halide crystals were prepared by the Bridgman method, followed in some cases by multiple-zone melting. The absorption spectra of these crystals were determined in the region of the long-wavelength edge, which is of approximately exponential shape and obeys fairly closely the $1/kT$ rule.[1] Cold work producing considerable deformation does not affect these absorption spectra. Small concentrations of cationic impurities such as Pb, Cu, Au, Ni, Cr, Co, and In produce absorption bands in and beyond the edge region. Reproducibility of the absorption spectra of pure crystals indicates that these spectra are not vitiated by impurities. Exposure to suitable wavelengths produces volume darkening of the crystals, which is extremely weak in the purest crystals, requiring special methods for its investigation. Cold work and certain impurities (Cu, Co, Au) enhance the darkening. In some cases, notably Au, the darkening process continues after exposure. The impurity bands of Ni and In are bleached by exposure. It is not known at present whether the darkening of the purest crystals is caused by residual impurities or strain or both.

[1] F. Urbach, Phys. Rev. 92, 1324 (1953).

T6. Silver Halide Phosphors. FRANK MOSER AND FRANZ URBACH, *Eastman Kodak Company.*—Crystals of simple and mixed silver halides are known to show a strong fluorescence but little afterglow at low temperatures. However, the slow buildup of luminescence under weak excitation indicates the presence of effective trapping processes. These processes have been studied in more detail on silver bromoiodide phosphors. The lifetimes of the trapping states were estimated by observing the dependence of buildup rates on the dark interval between two exposures. The trapping states are also revealed by the effects of red or infrared radiation. If applied during excitation, it reduces the stationary brightness; if applied in the interval between exposures, it reduces the rate of re-excitation. A simple model representing this behavior and the absence of phosphorescence predicts that the efficiency of the stationary luminescence should increase with the square root of the exciting intensity. This has been confirmed for a large range of the latter. By the introduction of small concentrations of suitable impurities, e.g., strontium, long afterglow, thermoluminescence, and stimulation by long wavelengths can be produced. These phenomena are described by a simple extension of the proposed model.

T7. Theory of Silver-Halide Photolysis. CHARLES A. DUBOC, *Eastman Kodak Company.*—G. Luckey[1] has interpreted his measurements of halogen evolution in the vacuum photolysis of silver halides as indicating that each photon absorbed within a thin surface layer releases one halogen atom, whereas the photoproducts of photons absorbed further from the surface are lost by recombination. A specific but very simplified model has been studied. Absorbed photons are assumed to create electrons and holes of equal mobility which then partly recombine within the crystal and partly diffuse to the surface to recombine by a different mechanism or to release halogen and silver. The law of volume recombination chosen is such that the model reproduces the observed intensity dependence of photoconductivity. Assuming the surface reaction to be intrinsically fast, its actual rate is determined by the rate of supply of electrons and holes by diffusion. This model permits one to calculate photolytic yields from a knowledge of photoconductivity, or vice versa, and gives the wavelength dependence of both phenomena. A preliminary comparison with experiment is promising, and a predicted reciprocity failure has recently been found experimentally by Luckey under certain conditions.

[1] G. Luckey, J. Phys. Chem. 57, 791 (1953).

T8. Some Photographic Effects in Single Crystals of Silver Bromide. W. WEST AND V. I. SAUNDERS, *Eastman Kodak Company.*—Observations on the photographic and related behavior of thin single crystals of silver bromide prepared from the melt will be described, following indications from the work of Boissonnas and of J. W. Mitchell and his co-workers that these crystals might constitute, within limits, a useful model of the grain of a photographic emulsion. As produced from the melt, the crystals, the surfaces of which were (100) faces, exhibited a relatively high surface and internal sensitivity. The surface sensitivity was characterized by low-intensity reciprocity failure, and the surface images were strongly reversed at high exposure-times, while the internal image exhibited high-intensity reciprocity failure and did not reverse over a wide range of exposures. The relative behavior of the surface and internal images is consistent with the bromination hypothesis of reversal. Preferential appearance of bromine at the intersection of substructural mosaic boundaries with the surface was indicated. Optical sensitization and supersensitization were reproduced in these crystals, the internal image associated with optical sensitization being found to a distance at least 1.4μ from the surface. The absorp-

tion spectrum of a monolayer of adsorbed dye on the crystal surface was measured, and the kinetics of adsorption was followed spectroscopically.

T9. Effect of Bromine on the Dark Conductivity of Silver Bromide and Its Relation to Photoconductivity. GEORGE W. LUCKEY, *Eastman Kodak Company.*—The dark conductivity of a silver-bromide crystal in a bromine atmosphere increases with increasing bromine pressure. Wagner[1] showed that the conductivity increase at temperatures above 200°C is caused by the formation of positive holes inside the crystal. His mechanism predicts that this hole conductivity should be proportional to the square root of the halogen pressure. The conductivity increases caused by various pressures of bromine vapor have been measured at temperatures between 25 and 200°C. Above 50°C, the increase in conductivity is proportional to the square root of the halogen pressure and independent of the crystal thickness. The data at 200°C agree with those of Wagner. Below 50°C, the results are more erratic, and the system reaches equilibrium slowly. The conductivity increases depend on the preparation of the silver halide samples. When the increases are large, the quantum efficiency of photoconductivity at room temperature is also large.

[1] C. Wagner, Z. physik. Chem. **B32**, 447 (1936).

T10. Ultra-Short Light-and-Voltage Pulses Applied to Silver-Halide Crystals by Turbine-Driven Mirror and Electrical Contacts. J. H. WEBB, *Eastman Kodak Company.*—Haynes and Shockley[1] studied electron mobility in silver-halide crystals using ultra-short light-and-voltage pulses. Their apparatus consisted of a radar-type pulse-forming network discharged by mercury spark tubes. An apparatus for carrying out this experiment has been developed using an air turbine with mirror and electrical contacts. Repetitive light pulses of 3 microseconds and voltage pulses of 10 kv and 20 microseconds can be applied to a crystal at a rate of 500 per second. The light-and-voltage pulses can be initiated simultaneously or with variable-time separation. The simplicity and practicability of the apparatus for electron mobility and photolysis studies on the silver halides will be illustrated by experimental results.

[1] J. R. Haynes and W. Shockley, Phys. Rev. **82**, 935 (1951).

SATURDAY MORNING AT 9:30

Calvert Room

(R. T. BIRGE presiding)

Lecture by the Recipient of the Buckley Prize

U1. Photoelectric Experiments on Excitation-Energy Transfer in Crystals. L. APKER, *General Electric Research Laboratories.* (40 min.)

Invited Papers

U2. Crystallographic Significance of Some Recent Results in Solid-State Physics. J. H. DONNAY, *Johns Hopkins University.* (30 min.)

U3. Paramagnetism of Solids. J. H. VAN VLECK, *Harvard University.* (30 min.)

U4. Spectroscopy of Solids. G. H. DIEKE, *Johns Hopkins University.* (30 min.)

SATURDAY MORNING AT 9:30

Phoenix Room

(S. G. WEISSBERG presiding)

Contributed Papers in High-Polymer Physics

V1. Experimental Study of the Behavior of Rubbers in Simple Shear.* J. E. IVORY,† F. P. BALDWIN,‡, AND R. L. ANTHONY, *University of Notre Dame.*—The dependence of shearing stress upon strain and temperature was investigated for two rubbers, GR-I-18 and Paracril-35. The type of strain employed was simple shear. Sandwich type specimens were used, and were so mounted as to permit free thermal expansion in a direction perpendicular to the plane of shearing. The stress relaxation method was used to obtain equilibrium stress-temperature curves, shearing displacements being held constant during the relaxation period and also during the stress-temperature runs. The stress-temperature curves were observed to be linear over a temperature range of 80°C for strains ranging from 0 to 15 percent. The stress-strain curves, obtained from the stress-temprature curves by cross-plotting, were also linear. A small internal energy component, amounting to about 5 percent of the total stress, was observed for each rubber. The existence of this component, whenever the rubber is permitted to expand freely in the direction perpendicular to the plane of shearing, is in agreement with the predictions of the statistical theory.

* Supported in part by the Office of Naval Research.
† Now with Bell Aircraft Corporation.
‡ Now at Esso Laboratories.

V2. Tensile Strength of Elastomers.* G. R. TAYLOR AND S. R. DARIN, *Mellon Institute.*—The tensile strength of decamethylene dis-methylazodicarboxylate vulcanizates of GR-S 50°C polybutadiene, 5°C polybutadiene, and natural rubber has been determined as a function of temperature and/or the

degree of cross-linking. A theory of tensile strength of amorphous polymers which adequately describes the effect of the degree of cross-linking on strength is proposed. The tensile strength is assumed proportional to the total number of active network chains in the vulcanizate times an explicit function of the degree of orientation of these chains at rupture. The resulting expression is shown to be adequate for GR-S, and when modified to take into account the effect of crystallization on the separate factors, it appears semiquantitatively correct for crystallizable polymers.

* The work discussed herein was performed as part of the research project sponsored by the Reconstruction Finance Corporation, Office of Synthetic Rubber, in connection with the Government Synthetic Rubber Program.

V3. Biaxial Creep Fracture of High Polymers. CHESTER G. BRAGAW, JR., *DuPont.*—An experimental investigation has been made of the creep fracture behavior of commercial polyethylenes subjected to uniaxial tension (simple tensile test) and biaxial tension (tube under internal pressure). A nonimpact loading was applied and held constant until fracture occurred. Direct stress-life data are presented for both cases and comparisons made. In biaxial tension a new creep embrittlement phenomenon was encountered; data from critical experiments are discussed and a structural mechanism is suggested. The discovery of extremely low ductility creep fracture under room temperature biaxial stressing implies that even in the case of the nonimpact loading of very ductile polymers, fracture behavior in multiaxial stress applications may be more important than deformation behavior.

V4. Unilateral Compression of Rubber. MICHAEL J. FORSTER, *Firestone Tire and Rubber Company.*—One-dimensional compression measurements have been made on samples of natural rubber gum stock. The experimental stress-strain curve and the theoretical relation $f=G[L-1/L^2)]$ agreed quite well over the entire range (0 percent–32 percent) studied. No hysteresis loop was evident. Volume measurements indicated the possibility of a slight increase in volume at low compressive strains, changing to a volume decrease at strains above 13 percent. The friction at the faces of the sample was eliminated by a new method of lubrication. The sample essentially floated between two tin films of a liquid which flowed under pressure between the sample and compressing plates allowing uniform lateral expansion of the sample.

V5. Behavior of Nonpigmented Rubber Vulcanizates in Tension. G. M. MARTIN, F. L. ROTH, AND R. D. STIEHLER, *National Bureau of Standards.*—Nonpigmented vulcanizates of Hevea, GR-S, GR-I, and Neoprene rubbers were subjected to constant tensile loads and their elongations were measured to the nearest 0.1 percent at intervals of time from 1 to 10 000 minutes. For temperatures between 25 and 55°C the elongations showed no tendency to become constant and in most cases they increased approximately with the logarithm of time. The stress-strain curves after a given period of creep could not be represented by any of the proposed theoretical stress-strain relationships. However, the curves for all vulcanizates of the four rubbers were similar up to about 200 percent elongation and could be represented by a single empirical stress-strain relation. This relation permits the calculation of the modulus near zero elongation and the stress-strain curve up to an elongation of 200 percent from a single stress-strain measurement.

V6. The Nature of Stark Rubber.* DONALD E. ROBERTS AND LEO MANDELKERN, *National Bureau of Standards.*—It has been demonstrated[1,2] that when slow heating rates are employed the melting temperature of undeformed natural rubber is independent of previous thermal history. This observation served as a basis for the assignment of 28±1°C as the equilibrium melting temperature $T_m°$, of natural rubber though it is well known that certain types of natural rubber, designated as "stark" exhibit appreciably higher melting temperatures. The melting behavior and x-ray diffraction patterns of four different samples of "stark rubber" were investigated. The melting temperatures ranged from 39 to 45.5°C while the x-ray diffraction patterns indicated that in all the samples, the crystallites displayed a preferred orientation. This orientation explains the higher melting temperatures that are observed and preserves the validity of the previous assignment of $T_m°$ for unoriented natural rubber. The orientation in "stark rubber" is probably caused by the plantation processing. Several methods which have been successful in preparing "stark rubber" in the laboratory will be outlined.

* Assisted by Office of Naval Research.
[1] D. E. Roberts and L. Mandelkern, Phys. Rev. 91, 225(A) (1953).
[2] D. E. Roberts and L. Mandelkern, J. Am. Chem. Soc. (to be published).

V7. Molecular Weight Distributions of Polymers: I. Speculations on Polymerizations to Equilibrium. JOHN LAUREN LUNDBERG, *Bell Telephone Laboratories, Inc.*—Writing weight and number average molecular weight sums in terms of standard changes in free energies of polymerization permits (1) circumscribing behavior of standard free energies of polymerization as functions of chain lengths, (2) describing reasonable molecular weight distributions at equilibrium, (3) limiting weight-number average molecular weight ratios to values close to unity, and (4) estimating lower limits in the million plus range for the average molecular weight of linear polyethylene at equilibrium. The relation between "ceiling temperatures" upon polymerization and standard free energies of polymerization is discussed. A method for obtaining values of thermodynamic functions for polymers and polymerization processes by measurements of molecular weight distribution and monomer activity at equilibrium is outlined.

V8. Glass Transitions in Polymer-Plasticizer Systems. LEO BREITMAN, *Polymer Corporation Ltd.*—Glass temperatures (T_g) of pure and plasticized elastomers have been obtained from dilatometric measurements and from the temperature dependence of angular response to torsional stress. The depression of T_g by a diluent, determined by either method, is a convenient measure of its low-temperature plasticizing efficiency. High-melting diluents generally had zero efficiency. Some compounds, though normally crystalline above T_g, depressed the glass temperature of polymer blends. These phenomena are interpreted in terms of phase separation in binary systems, including the effect of polymer on the freezing point of diluent. T_g decreased as the polymer loading increased to a more or less well defined limit, beyond which further dilution had negligible effect. For diester type plasticizers both $T_{g\,max}$ and the limiting diluent concentration were linear functions of compatibility, as defined by the extent to which standard polymer vulcanizates were swollen by plasticizer. Investigations with hydrocarbon oils showed that the apparent activation energy for flow (E_v) of the oil correlated with its low-temperature plasticizing efficiency, while four points and T_g of the oils were not as significant. It is concluded that low E_v and high compatibility with polymer are properties which mitigate for low-temperature plasticizing efficiency.

V9. Proton Magnetic Resonance in Polyamides. W. P. SLICHTER AND J. M. MAYS, *Bell Telephone Laboratories.*—Measurements have been made of the proton magnetic resonance absorption in several linear polyamides from −195° to +140°C. The variation of line width with temperature is similar in form to that found in other polymeric systems.[1] A marked decrease in line width with increasing temperature occurs over a span of 20 or 30 degrees within the range from 0° to 120°C, and is presumed to result from the onset of rotation of chain segments. In a series of polyamides possessing an

even number of carbon atoms between polar groups, this transition occurs at lower temperatures as the hydrocarbon portions are made longer (polydecamethylene octadecanamide compared to polyhexamethylene adipamide). In the copolymer polyhexamethylene adipamidesebacamide, the transition region is at a lower temperature than in the pure adipamide or the pure sebacamide. X-ray diffraction studies on fibers of all these substances show that the chain packing becomes more symmetrical over these same temperatures.

[1] R. Newman, J. Chem. Phys. **18**, 1303 (1950); Holroyd, Mrowca, and Guth, J. Appl. Phys. **22**, 696 (1951).

V10. Nuclear Magnetic Resonance Relaxation Times for Polyisobutylene in Carbon Tetrachloride Solution.* A. W. NOLLE, *The University of Texas.*—The nuclear magnetic resonance relaxation times are examined by the spin echo method, as a function of concentration, in solutions of high molecular weight polyisobutylene (molecular weight $>10^6$) in carbon tetrachloride. The hydrogen signal is used. Since the solvent is nonhydrogenous, the results are attributable to the kinetics of the polymer molecules. As the concentration is decreased, the transverse relaxation time (T_2) at 25°C increases sharply, until a value of the order of 70 milliseconds is reached at a concentration of 0.06 g of polymer per milliliter of solvent. The result then remains nearly constant with further decrease of concentration, indicating that the limiting behavior in dilute solution has been observed.

* Supported by the Office of Naval Research.

SATURDAY AFTERNOON AT 2:00

Shriver Hall, J.H.U.

(FRANK HERMAN presiding)

Invited Paper

W1. Cyclotron Resonance in Semiconductors. B. LAX, *M.I.T.* (30 min.)

Cyclotron and Electron-Spin Resonance

W2. Quantum Theory of Cyclotron Resonance for Degenerate Bands. J. M. LUTTINGER, *University of Michigan.*—Recently the author (in collaboration with W. Kohn) has given the rigorous quantum theory of cyclotron resonance for degenerate bands. For nondegenerate bands the classical theory and quantum theory give identical results. This theory has now been applied to the case of holes in Si and Ge, the top of the valence band in these materials being degenerate. Full account has been taken of the effects of spin orbit coupling. It turns out that if the external magnetic field is in the (111) direction the resulting coupled differential equations may be solved rigorously, under two assumptions: (1) The momentum along the external field is negligible. (2) The interaction of the electronic spin with the external field is ignored. The first assumption is certainly justified if we are interested in studying transitions at extremely low temperature (say below 1°K), which is where we would expect quantum effects to be most important. The second assumption is not quite so good for the lowest levels, the error being of the order of the ratio of the effective mass to the true electronic mass. This ratio is, in all likelihood, rather less than unity for all cases of interest, and the corrections are easily obtained via perturbation theory. Detailed results will be presented.

W3. Boltzmann Theory of Cyclotron Resonance for Warped Spherical Energy Surfaces.* H. J. ZEIGER, *M.I.T.*—A solution of the Boltzmann transport equation has been obtained with applied dc magnetic and rf electric fields, for constant energy surfaces of the form $\epsilon=[1+g(\theta,\phi)]\hbar^2k^2/2m$. Here (k,θ,ϕ) are spherical coordinates in k-space, referred to the magnetic field direction as z axis, and $g(\theta,\phi)$ is a small nonspherical term. The extension to DC electric fields follows directly in the zero frequency limit. The collision time is assumed constant and a first order solution for the perturbed part of the distribution function is obtained as a Fourier series in ϕ. This leads to an expression for rf current, as a sum of terms $\mathbf{J}_n(\theta)$. The terms contain resonant denominators, with $n=1$ corresponding to the fundamental cyclotron resonance, and higher values of n corresponding to harmonics. The magnetic field for resonance depends on field direction, and on θ (or k_z). When integrated over θ the resulting expressions for $\mathbf{J}_n$ describe the general features of the fundamental cyclotron resonance in the valence bands of Ge and Si. The theory is consistent with the possible observation of a third harmonic of the fundamental high mass hole resonance in Ge.[1]

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

[1] R. N. Dexter, following abstract.

W4. Third Harmonic Cyclotron Resonance of Holes in Germanium.* R. N. DEXTER, *M.I.T.*—In germanium the marked anisotropy of line shape and of magnetic field for cyclotron resonance of the heavy holes has indicated that the valence band energy surfaces are warped spheres.[1] We have observed an additional anisotropic resonance of weak intensity seen earlier in two orientations[2] but not explained. The resonance occurs at fields one third those giving resonance of the heavy holes. In the (110) plane, the new resonance disappears when the magnetic field is parallel to the [111] direction but has about one sixth the intensity of the heavy hole resonance when the field is 35° from the [001] direction. We have proposed that the new resonance of heavy holes arises from the anharmonic motion along the anisotropic energy contours. No second harmonic resonance has been observed. A classical Boltzmann transport theory for the valence band energy surfaces has shown a detailed agreement with the observations described above. Theoretically, the second harmonic is relatively suppressed by symmetry.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

[1] Dexter, Zeiger, and Lax, Phys. Rev. **95**, 557 (1954).
[2] A. F. Kip, Physica (to be published).

W5. Cyclotron Resonances in Germanium at 1.4°K. R. C. FLETCHER, F. R. MERRITT, AND W. A. YAGER, *Bell Telephone Laboratories.*—We have measured the cyclotron resonances on several high resistivity samples of germanium ($N_A\approx N_d\approx 10^{13}$ cm^{-3}) with a Zeeman Modulation Spectrometer at a frequency of 24 kmc both at 4.2°K and 1.4°K. Carriers of both signs

were introduced with white light. At 4.2°K we have found the previously reported[1] resonances characteristic of both holes and electrons. When the sample temperature was decreased to 1.4°K, the electron resonances increased in peak absorption and became sharper. The hole resonances, however, completely disappeared, with no new resonances of comparable magnitude appearing in the range from $m^* = 0.01$ to 3. The disappearance of the normal hole resonances is what the quantum treatment of Kohn and Luttinger[2] would predict for carriers near a band degeneracy. The absence of the predicted new hole resonances is not understood. The narrowing of the electron resonances at 1.4°K suggests that impurity scattering, which Hall mobility measurements indicate is the dominant scattering mechanism at these temperatures, either does not contribute significantly to the broadening of cyclotron resonances or else contributes less as the temperature is decreased.

[1] Dresselhaus, Kip, and Kittel, Phys. Rev. 92, 547 (1953); Lax, Zeiger, Dexter, and Rosenblum, Phys. Rev. 93, 1418 (1954); Dexter, Zeiger, and Lax, Phys. Rev. 95, 557 (1954).
[2] Kohn and Luttinger, Phys. Rev. 96, 529 (1954).

W6. Effective Mass of Carriers and Relaxation Time in Germanium.* F. D'ALTROY AND H. Y. FAN, *Purdue University.*—Relaxation time and effective mass of carriers have been evaluated for *n*-type germanium using dielectric constant K and conductivity σ obtained from microwave (9200 Mc/sec) transmission measurements. Four samples were used and at each of the four temperatures: 20°K, 78°K, 200°K, and 300°K, results were obtained on two different samples. The values of m_s/m obtained are 0.18, 0.21, 0.40, and 0.58 for the four temperatures, respectively. The estimated error is ±20 percent. The values for two different samples at each temperature are in close agreement, although the relaxation times for the two samples used at 20°K differ by a factor of 2.2. The value for 300°K agrees with the results of Benedict and Shockley, whereas the value for 20°K approaches the value expected from cyclotron resonance measurements. Measurements at the same temperatures have been reported previously for *p*-type germanium.[1] The value obtained is $m_h = (0.34 \pm 0.06)m$ at all temperatures (the value reported was $m_h = 0.43m$ due to an error in the estimation of carrier concentrations). Preliminary measurements on *p*-type germanium at 4.2°K gave $\Delta K > 0$, which can be attributed to bound holes on the acceptors.

* Work supported by a Signal Corps Contract.
[1] F. D'Altroy and H. Y. Fan, Phys. Rev. 94, 1415 and 1405 (1954).

W7. Absorption by Free and Bound Holes in *p*-Type Germanium. S. TEITLER AND M. LAX, *Syracuse University,* AND E. BURSTEIN, *Naval Research Laboratory.*—The optical absorption due to free holes in *p*-type germanium is explained on the gasis of interband transitions using the present picture of the valence bands, with two bands degenerate at $k = 0$, and a third band, split off at $k = 0$. The respective mean effective masses for small k are $m_1 = 0.3m$, $m_2 = 0.04m$, and $m_3 = 0.07m$ from cyclotron resonance data. Assuming spherical energy surfaces and matrix elements proportional to k, we obtain an absorption curve with three peaks, at room temperature. The experimental[1] location of these peaks is used to obtain the effective mass of the third band, $m_3 = 0.079m$, and also the energy gap between the first and third bands, $E_g = 0.28$ ev, which is the right order of magnitude for spin-orbit splitting.[2] The optical absorption at helium temperatures in the 4μ region is calculated on the basis of transitions by bound holes to the third valence band and yields an absorption curve in reasonable agreement with experiment.

[1] H. B. Briggs and R. C. Fletcher, Phys. Rev. 91, 1342 (1953).
[2] A. H. Kahn (unpublished) has recently discussed spin-orbit splitting and optical absorption by free holes in *p*-type germanium.

W8. Temperature Effect of Paramagnetic Line Shape. E. P. GROSS, *Syracuse University.*—The theory of spin absorption involves application of time dependent perturbation theory to a system nearly canonically distributed. In absence of the applied field the states are assumed to form a nondegenerate continuum; the absorption depends on the density of states. The moment method of Waller relates the moments of the absorption to the averages of functions of the dipole moment operator and its time derivatives taken for a canonical distribution. These results hold at infinite temperatures. We extend the theory by relating the operator averages to weighted moments of the absorption; the weight factor is a function of $h\omega/kT$. The approach differs from other finite temperature theories in that no direct attempt is made to compute the unweighted moments. We point out the identical basis of spin absorption theory and the fluctuation-dissapation analysis of irreversible thermodynamics. One of the relations derived here is the generalized Nyquist formula; the others provide an infinite set of connections between the "fluctuating" and irreversible aspects of systems satisfying the assumptions of the theory.

W9. Spin Resonance Widths of Electrons in Donor States in Silicon.* W. KOHN, *Carnegie Institute of Technology.*—Honig and Kip and Honig have reported the widths of spin resonance lines due to electrons bound by Li and As impurities in silicon. We have made theoretical estimates of these widths, which are apparently due to the magnetic moments of the Si^{29} isotope. The model was the same as that which was used to account for the hyperfine splitting of bound electron states associated with P donors. One somewhat uncertain factor enters all these calculations namely

$$\eta = |\psi(k^{(1)},0)|^2/\Omega^{-1}\int_{\text{cell}} |\psi(k^{(1)},r)|^2 dr,$$

where $\psi(k^{(1)},r)$ is a Bloch wave at the bottom of the conduction band and Ω is the volume of the cell. By adjusting η to give agreement with experiment we find

	P, h.f. splitting	Li, line width	As, line width
η	≈200	160	≲260

(If $k^{(1)}$ should lie extremely close to either the center or the boundary of the Brillouin zone, the measured line widths would require smaller values of η). If $\psi(k^{(1)}r)$ were completely s-like we estimate $\eta \approx 700$. This indicates a very substantial admixture of p-state.

* Supported in part by the Office of Naval Research.

W10. Spin Resonance in Neutron Irradiated Silicon.* E. SCHULZ-DUBOIS, M. NISENOFF, H. Y. FAN, AND K. LARK-HOROVITZ, *Purdue University.*—Electron spin resonance has been observed in *p*-type, boron-doped silicon after irradiation by neutrons.[1] The measurements were made at 4.2°K and at 9200 Mc/sec. The absorption line gives a gyromagnetic ratio $g = 2.004 \pm 0.001$ determined by using diphenyl picryl hydrazyl calibration. The line width between half power points is about 12 oersted. The room temperature resistivity ρ was increased from 0.01 to 10^4 ohm-cm by the irradiation.[2] Another sample from the same piece was partially annealed after the irradiation, $\rho = 3$ ohm-cm; it showed weaker absorption with $g = 2.002 \pm 0.001$ and a half width ~3 oersted. The samples had etched surfaces. A 500 ohm-cm sample, not irradiated, gave no resonance absorption with the same surface treatment. Resonance absorption has not been found in boron-doped silicon with or without partial compensation by donar impurity.[3] The observed absorption should therefore be associated with the defects produced by the irradiation.

* Work supported by a Signal Corps and U. S. Atomic Energy Commission contract.
[1] We are indebted to J. Crawford and J. Cleland of Oak Ridge National Laboratories for the irradiation.
[2] K. Lark-Horovitz, *Semi-conducting Materials* (Butterworths, London, 1951).
[3] Fletcher, Yager, Pearson, Holden, Read, and Merritt, Phys. Rev. 94, 1392 (1954).

W11. Multiple Resonances in Cobalt Ferrite.* P. E. TANNENWALD AND H. J. ZEIGER, *M. I. T.*—In the past, most microwave experiments on single crystals have been carried out on the assumption that the magnetization vector was fully aligned with the applied magnetic field. B. Lax has suggested that in high anisotropy cubic crystals, when the magnetic field H_0 is applied in certain crystal directions (other than the easy axis), ferromagnetic resonance might occur before the magnetization vector M is lined up with H_0, in addition to the usual resonance. We derived a very general solution of the equation of motion of the magnetization vector which includes the effects of anisotropy in terms of energy rather than effective demagnetizing factors[1] and applied it to a cubic crystal. We have observed double resonances as a function of H_0 at 24 000 Mcps in a single crystal of cobalt ferrite. Data will be presented from which the anisotropy and g-factor can be calculated; and the extent to which the assumptions made in the theory are justified will be discussed.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

[1] Similar to that first given by J. Smit, Conference on Ferrimagnetism, NOL, October, 1954; and H. Suhl (submitted to Phys. Rev.).

SATURDAY AFTERNOON AT 2:00

Rowland 205, J.H.U.

(H. J. WILLIAMS presiding)

Invited Papers

X1. Quenching-in of Vacancies in Pure Gold. J. S. KOEHLER, *University of Illinois.* (30 min.)
X2. The Magnetic Structure of Iron. C. G. SHULL, *Oak Ridge National Laboratory.* (30 min.)

Ferromagnetism and Ferroelectricity

X3. Antiferromagnetism in a Cr_2O_3 Crystal. T. R. MCGUIRE, E. J. SCOTT, AND F. H. GRANNIS, *U. S. Naval Ordnance Laboratory.*—The magnetic susceptibility and microwave resonance absorption of a Cr_2O_3 single crystal have been investigated. The crystal was prepared by the flame fusion method. It has rhombohedral symmetry and showed an antiferromagnetic Curie temperature (Tc) of 307°K. Below *Tc* the susceptibility (χ) perpendicular to the [111] direction is independent of temperature while the value of χ parallel to [111] approaches zero at very low temperatures. According to the Van Vleck[1] theory, this behavior indicates that the spins are aligned along the [111] direction. Above 77°K the parallel susceptibility was found to be proportional to the $\frac{1}{2}$ power of the temperature. Resonance measurements (22 500 mc) at the Curie temperature showed a shift in the peak of the absorption curve as a function of temperature. This shift was towards lower magnetic fields and will be discussed in terms of the Kittel[2] resonance theory which includes the anisotropy and exchange fields in addition to the applied field.

[1] J. H. Van Vleck, J. Chem. Phys. **9**, 85 (1941).
[2] C. Kittel, Phys. Rev. **82**, 565 (1951).

X4. Ionic Distribution in Magnesium Ferrite.* C. J. KRIESSMAN AND S. E. HARRISON, *Remington Rand Inc.*, AND H. B. CALLEN, *University of Pennsylvania.*—Magnesium ferrite samples have been sintered at 1400°C and water quenched at nine temperatures (T_q) between 1400°C and 400°C. The fraction x of Mg^{++} ions in tetrahedral sites has then been determined by measurements of the saturation magnetization. The values of x vary from 0.09 for $T_q = 450$°C to 0.32 for $T_q = 1400$°C. This latter value has been substantiated using x-ray diffraction techniques by Miss S. Greenwald of the Naval Ordnance Laboratory. The data do not fit the distribution proposed by Neel,[1,2] $x(1+x)/(1-x)^3 = e^{-\theta/T}$, where θ is a constant. The data do fit a distribution in which $\theta = \theta_0 - \theta_1 x$, implying that the number of Mg^{++} ions already on tetrahedral sites cooperatively decreases the activation energy necessary for the transition to tetrahedral sites. A mechanism qualitatively able to account for the form of θ is the dependence of the Madelung energy on the ionic distribution. The form of the various terms in the Helmholtz potential and the consequent physical significance of the parameter θ_1 will be discussed.

* Supported in part by the Office of Naval Research.
[1] L. Neel, Comptes rend. **230**, 190 (1950).
[2] R. Pauthenet and L. Bochirol, J. phys. radium **12**, 249 (1951).

X5. Curie Constant, Spontaneous Polarization, and Latent Heat in the Ferroelectric Transition in $KNbO_3$. S. TRIEBWASSER AND J. HALPERN, *IBM Watson Laboratory.*—Measurements of the dielectric constant of $KNbO_3$ single crystals above the tetragonal to cubic transition temperature indicate that the Curie law $K = C/(T - T_0)$ is followed quite closely with $C = 2.68 \times 10^4$°C and $T_0 = 350$°. Observation of the hysteresis behavior in the tetragonal ferroelectric state yields a value of spontaneous polarization P_s in the vicinity of the transition of 26 $\mu C/cm^2$. If one assumes the form of the Electric Gibbs function as given by Devonshire,[1] then the constants C and P_s are related to the latent heat of the ferroelectric transition by

$$\Delta S = L/T_c = (2\pi/C)P_s^2,$$

where T_c is the temperature of the transition and L the latent heat. We have repeated the measurement of the latent heat previously given by Shirane *et al.*[2] arriving at a somewhat lower value of 134±5 cal/mole. This is in reasonable agreement with the value 150 cal/mole derived from C and P_s reported above.

[1] A. F. Devonshire, Phil. Mag. **3**, 85 (1954).
[2] Shirane, Danner, Pavlovic, and Pepinsky, Phys. Rev. **93**, 672 (1954).

X6. Electromechanical Behavior of Single Crystals of $BaTiO_3$. E. J. HUIBREGTSE, M. E. DROUGARD, AND D. R. YOUNG, *IBM, Poughkeepsie.*—The frequencies of resonance and antiresonance of the fundamental modes of vibration have been measured in single crystals of $BaTiO_3$, in the temperature range from room temperature to 135°C. The samples were cut into simple geometrical shapes, long bars and flat disks, to insure that the fundamental modes were being excited. To

make calculations of various physical constants a knowledge of mode is necessary. All the crystals were "*c*" plates (i.e., the direction of polarization is perpendicular to large area sides), and the large area sides were as completely electroded as possible, to minimize a clamping effect caused by nonelectroded portions of the crystal. Results include the temperature dependences of: the electromechanical coupling coefficients, k_1 and k_r (for longitudinal and radial modes, respectively); the elastic compliances at constant field S_{11}^E and for constant polarization S_{11}^P, the piezoelectric coefficient d_{31}, and Poisson's ratio μ. At and above 120°C, the Curie temperature, the crystal structure is cubic and is no longer piezoelectric. By applying a dc field, the electrostrictive effect distorts the cubic structure into a tetragonal structure, which is again piezoelectric. Above the Curie temperature the electromechanical behavior has been studied as functions of both temperature and electric field, and these results will be presented.

X7. Second-Order Transition in $BaTiO_3$. A. deBRETTEVILLE, JR., *Signal Corps Engineering Laboratories.*—The paraelectric to ferroelectric transition of a barium titanate crystal grown by the Reimeika[1] technique is established as a first-order transition.[2] Double hysteresis loops indicate that the transition changes into a second order one approximately 8° above the Curie point. Photographs of double hysteresis loop show that the polarization as a function of field strength does not rise abruptly as for a first-order transition. Free energy curves derived from the measurements assume a zero slope at 123°C, approximately where the latent heat becomes zero. At this temperature the reciprocal dielectric constant shows a definite change in slope.

[1] Crystals obtained through the courtesy of Dr. S. O. Morgan, Bell Telephone Laboratories, Murray Hill, New Jersey.
[2] W. J. Merz, Phys. Rev. 91, 513–517 (1953).

X8. Dielectric Behavior of Barium Titanate in the Paraelectric State. M. E. DROUGARD, R. LANDAUER, AND D. R. YOUNG, *IBM, Poughkeepsie.*—The coefficients in the equation of state of $BaTiO_3$ proposed by Devonshire can be considered as describing the polarization and temperature dependence of the dielectric constant. This dependence has been studied by a dynamic method. The polarization is developed by a large amplitude af field and the dielectric constant is measured by measured by a small rf signal. This method provides an accurate measurement of the coefficient of the P^6 term in Devonshire's expansion of the free energy. It is shown, however, both by calculations and experimentally that this coefficient is quite sensitive to clamping and that special precautions have to be taken to obtain reliable results. This coefficient has been studied as a function of temperature from the Curie point up to 150°C. It has been found to vary by 50 percent in that range of temperature, showing a linear decrease in magnitude with increasing temperature. No reliable results have been obtained on the coefficient of the P^6 term. The accuracy of the results is impaired by a hysteresis phenomenon which has not been explained, and the highest fields that could be applied without damaging the sample do not allow the detection of any contribution due to the P^6 term, even just above the transition temperature.

SATURDAY AFTERNOON AT 2:00

Remsen 1, J.H.U.

(S. MROZOWSKI presiding)

Carbons

Y1. Self-Diffusion in Natural Graphite Crystals.* M. A. KANTER, *Argonne National Laboratory and Illinois Institute of Technology.*—A radioactive tracer technique has been used to measure diffusion in graphite crystals which were separated from limestone and suitably purified. These were small particles, *ca.* 10^{-1} cm in diameter and 10^{-3} thick, and were composed of several single-crystal regions with some misaligned material at the edges amounting to no more than about one percent. The experiments were carried out by heating several hundred of these particles to temperature in radioactive carbon monoxide whose C^{14} concentration was maintained constant and then determining the uptake of tracer in the crystals. At 1600°C the tracer exchanged with the graphite surface in a matter of minutes. At 1950°C diffusion into the imperfect regions of the crystal began at a measurable rate. Above 2150°C, diffusion into the single crystal regions predominated, and the measurements agreed with equations for diffusion into a semi-infinite solid whose surface concentration is maintained constant. The activation energy for volume diffusion in graphite calculated from these data is about 170 k cal/mole.

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.

Y2. Two-Medium Theory of Thermal Conductivity of Artificial Graphite: Experimental.* ALAN W. SMITH, *North American Aviation, Inc.*—The two-medium nature of pitch-bonded artificial graphite has been offered as an explanation for the low-temperature thermal conductivity of this material.[1] This is anomalous in that the thermal conductivity has a stronger temperature dependence than the specific heat. Measurements have been made recently on large crystallite natural graphite and small crystallite, nonpitch-bonded artificial graphite (obtained from J. C. Bowman, National Carbon Company). The low-temperature thermal conductivity of these two graphites has the same temperature dependence as the specific heat. This is the normal behavior of crystals exhibiting boundary scattering. Measurements have also been made on brominated, pitch-bonded artificial graphite (obtained from G. Hennig, Argonne National Laboratory). Bromination to 1.16 atom percent decreases the thermal conductivity by a factor of 2.5. This effect is explained by the two-medium theory in the subsequent paper.

* This paper is based on studies conducted for the U. S. Atomic Energy Commission.
[1] A. W. Smith, Phys. Rev. 93, 952 (1954).

Y3. Two-Medium Theory of Thermal Conductivity of Artificial Graphite: Interpretation.* JOHN E. HOVE, *North American Aviation, Inc.*—As mentioned in the previous paper, the observed low-temperature thermal conductivity of pitch-bonded artificial graphites shows an anomalous temperature dependence, while both large crystal natural and nonpitch-bonded artificial graphites have a normal behavior. This paper will show how this can be quantitatively explained by the presence in the artificial graphites of ungraphitized carbon

derived from the bonding pitch. Furthermore, this two-medium theory correlates the observed effects of bromination with the effects expected on the basis of previous work. The graphite crystallites will conduct heat in nearly a two-dimensional manner; it is assumed that the ungraphitized carbon medium is similar to a highly disoriented diamond structure and can be considered as three-dimensionally isotropic. By taking these two regions to be in series, an expression for the total thermal conductivity is derived which qualitatively describes the observed data. By a quantitative fit, estimates of crystallite size and interparticle distance are obtained; these check previous estimates (by other methods) in a satisfactory manner for the three types used (large and medium particle coke and small particle lampblack graphites). Brom-graphite residue compounds introduce additional scatterers (i.e., bromine) presumably at crystallite and mosaic boundaries only. The data of the previous paper are analyzed by the two-medium theory and are shown to support the above view.

* This paper is based on studies conducted for the U. S. Atomic Energy Commission.

Y4. Thermal Conductivities of Carbons and Graphites.* C. P. JAMIESON, *University of Buffalo* (introduced by S. Mrozowski).—The thermal conductivities, κ, of pitch-bonded, extruded carbon rods have been measured for ambient temperatures, T, ranging from 110°K to 400°K, each rod having been heat-treated to a different temperature (Ht) between 1200°C and 3100°C. Power was supplied to a heater at the middle of the rod whose ends were in thermal contact with the bath. Heat losses were reduced by a radiation shield with matched temperature gradients and by evacuation of the chamber. For highest Ht's, plots of κ *versus* T show maxima at or below room temperature; for lowest Ht's, κ increases approximately linearly with T. Mean crystallite diameter, which increases with increasing Ht, was determined by x-ray diffraction techniques. For a fixed T, the thermal resistivity, R, depends on mean crystallite diameter in such a way that for Ht less than 2200°C, R increases much more strongly than linearly with the reciprocal of mean crystallite diameter. This indicates that besides the usual boundary and lattice scattering there is additional scattering, probably due to intercrystalline effects.

* Work supported in part by the Office of Naval Research and also in part by the U. S. Atomic Energy Commission.

Y5. Temperature Dependence of Magnetic Susceptibility of Carbons and Polycrystalline Graphites.* P. KIIVE AND H. T. PINNICK,† *University of Buffalo*.—The magnetic susceptibility χ of soft-carbon rods heat-treated to temperatures of $Ht = 1600$°C, 1800°C, 2000°C, 2200°C, 2400°C, and 2800°C was measured at seven temperatures T between 80°K and 1300°K. Moreover, χ as a function of T for all heat treatments, is similar to that of large crystals of graphite.[1] χ reaches a practically temperature-independent maximum value at low-temperatures T and tends to zero linearly with $1/T$ at high temperatures. All curves χ *versus* $1/T$ for different heat-treatments join the curve for well-graphitized material in the high temperature range, but, at low temperatures, curves for Ht lower than 2200°C reach smaller maximum values, the values decreasing with decrease in Ht (decrease in microcrystallite diameters) in a manner similar to that found from measurements made at room temperature.[2] The detailed interpretation of these relationships in terms of electron gas diamagnetism is not clear at present.

* Work supported by the Office of Naval Research.
† Now at Electro Metallurgical Company, Niagara Falls, New York.
[1] W. Ganguli and K. S. Krishnan, Proc. Roy. Soc. (London) **117**, 168 (1941).
[2] H. T. Pinnick, Phys. Rev. **95**, 846 (1954).

Y6. Magnetic Resonance Properties of Raw Cokes.* J. G. CASTLE, JR., *University of Buffalo*.—Raw coke may be designated as any carbonaceous matter which has been heated to a temperature (Ht) between 300°C and 700°C. Recently Uebersfeld[1] and Ingram[2] found spin-resonance absorption in activated charcoal, charred carbohydrates, and coal. Early in our program on the magnetic resonance properties of carbons and graphites, we had independently found a single sharp absorption near $g = 2$ in several raw cokes. The room temperature absorption of 3-cm radiation in each coke occurs at $g = 2.0030 \pm 0.0002$. The absorption intensity rises with increasing Ht (increasing molecular size) to a maximum near 550°C and then drops several orders of magnitude as the volatile material is driven off, as in coal cokes.[2] On the basis of experiments on a wide variety of cokes, we believe this absorption is due to nitrogen or oxygen bonded into the coke structure. The lines are approximately Lorentz-shaped. We find different line widths in the various raw cokes; the full widths at half-maximum range from 3 to 12 gauss. Some coke samples have a strong, broad absorption line with a g-value of about six.

* Work supported by the Office of Naval Research.
[1] Uebersfeld *et al.* Nature **174**, 614 (1954).
[2] Ingram and Tapley, Nature **174**, 797 (1954); Ingram and Bennett, Phil. Mag. **45**, 545 (1954).

Y7. Dimensional Changes During Heat Treatment and Thermal Expansion of Polycrystalline Carbons and Graphites.* F. M. Collins, *University of Buffalo*.—Two telescopes with micrometer eyepieces were used to determine the length changes of carbon samples placed within a furnace. These were rods made by extrusion of calcined coke-pitch mixtures and baked to 1100°C. The irreversible length changes were measured as the temperature was gradually raised from 1100°C to 2800°C, as were the reversible-thermal contractions of the resultant graphites while the temperature was lowered. Soft-carbon rods contract in heat treatment up to 1500°C and then expand, rapidly for the next few hundred degrees and more slowly thereafter. Both the heat-treatment curves and the thermal-expansion curves of graphite markedly depend on the calcination temperature of the coke; x-ray diffraction reveals corresponding differences in structure of the resulting graphite. Changes in expansion coefficient of graphite due to impregnation with pitch are less for rods impregnated after being baked to temperatures above 1100°. The results indicate that introduction of the binder affects the subsequent development of the crystalline structure in the heat-treatment process.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Y8. Physical Properties of Carbons and Porosity.* S. MROZOWSKI, *University of Buffalo*.—The dependence of different physical properties of carbons and polycrystalline graphites upon the porosity introduced in the manufacturing process is considered. The apparent (bulk) density d of the material is a function of two variables: the density of the coke particles d_0 (mass of coke per unit volume of bulk material) and the density of binder coke $(d - d_0)$. Making a number of simplifying assumptions as to the distribution of the binder coke and as to the statistics of the interparticle contacts the following relations are derived: for the elastic modulus $E = A \cdot d_0(d - d_0)$ for the mechanical strength $S = \beta \cdot d_0^{1+x} \times (d - d_0)$ and for the electric (and heat) conductivity $\sigma = C \cdot d_0^{\frac{1}{3}}(d - d_0)^{\frac{1}{3}}$ where $0 \leqslant x \leqslant 1$ and where the coefficients A, B, and C are proportional to the respective values for the dense material (d_{max}). Furthermore, C is inversely proportional to R^2 (R-average radius of coke particles) and also depends on the dimensions of the specimen. Since the maximum amount of binder decreases with increase of d_0 it is shown that the highest conductivities obtainable for unimpregnated carbons and graphites made by the standard method are expected to

increase first and then (for $d>1.75$) decrease with increase of the bulk density of material.

* Work performed in part under the auspices of the U. S. Atomic Energy Commission.

Y9. Studies of Elastic Modulus of Carbons.* K. HONG AND S. MROZOWSKI, *University of Buffalo.*—The dependence of Young's Modulus E on the heat treatment was investigated for extruded-carbon rods made essentially of a soft-type coke. The rods were subjected to static bending moment at room temperature. It was found that for increasing heat-treatment temperatures Ht the modulus first rapidly decreases (decrease by a factor of 2 between 1200° and 2000°C) and after going through a minimum at $Ht=2000$°C begins to increase. Around $Ht=2400$°C a maximum is reached after which the modulus gradually decreases up to highest heat treatments used (2900°C), the last value being, however, still higher than the value at the minimum. The dependence of E and of the electric conductivity σ on the bulk density was investigated for a group of rods from the same batch. The experimental data can be represented by $E=\alpha_1(d-d_0)$ and $\sigma^2=\gamma(d-d_0)$ where α and γ are constants depending on heat treatment and d_0 the density of coke particles (see preceding paper). The results are in agreement with the theoretical expectations. The agreement of extrapolated d_0 as determined from the different series of experiments shows that the spread in density is due mainly to variations in the coke yield of the binder and demonstrates the feasibility of a determination of a particle coke content d_0 for carbons of an unknown composition.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Y10. Density-Resistivity Relationships in Baked Carbons.* E. J. SELDIN, *University of Buffalo.*—Carbon samples were molded from mixtures of particles of calcined petroleum coke and coal tar pitch binder, and were then baked to 1000°C. The density d and the electrical resistivity ρ were determined as well as d_0, the density of the coke particles (for definition see the preceding paper by S. Mrozowski), and $d-d_0$, the density of the coked binder. All samples were made of single-sized coke particles. By varying the degree of compression a wide range d and d_0 was obtained. Some groups of samples were impregnated with pitch and rebaked, the process being repeated several times; in this way the density of a sample was increased while its d_0 remained almost unchanged. For samples with the same d_0 the relationship $1/\rho^2=\gamma\cdot(d-d_0)$ was found to hold. For samples with different d_0 preliminary measurements show that $\gamma=C^3\cdot d_0^n$ where $3\leqslant n\leqslant 4$. The factor C was found to be independent of particle size and nearly the same for samples made with a wide range of binder contents with the exception that for samples of very low-binder content C is considerably higher.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

SATURDAY AFTERNOON AT 2:00

Remsen 101, J.H.U.

(C. HERRING presiding)

Semiconductors, III

Z1. Surface Potential and Surface Charge Distribution from Semiconductor Field Effect Measurements. W. L. BROWN, *Bell Telephone Laboratories.*—It has recently become apparent that from measurements of the change of conductance of a semiconductor with application of an electric field normal to its surface (the "field effect") one can determine both the surface potential (the electrostatic potential of the surface relative to the interior of the semiconductor) and the dependence of the immobile charge in electronic surface states on this surface potential. There is a minimum in the conductance of the space-charge layer at the surface as a function of the applied-electric field. It arises as majority carriers are depleted from the surface region, decreasing the conductance, and minority carriers are introduced in an inversion layer at the surface, increasing the conductance. This minimum can in principal always be obtained with large enough electric fields. When the minimum is experimentally observed, the measured changes of conductance with field can be compared directly with those expected in the absence of surface states to give the surface potential and the immobile surface charge. This method will be described as applied to measurements on a particular germanium surface.

Z2. Field Effect in Germanium. H. C. MONTGOMERY AND W. L. BROWN, *Bell Telephone Laboratories.*—The effect of a transverse electric field at one surface of a germanium filament on its conductance was observed for external fields up to $\approx 10^5$ volts/cm, at frequencies up to a few kilocycles. Oscillograms showing conductance as a function of charge induced in the surface region were obtained for n- and p-type material at temperatures 175–300°K. In either type material, a single oscillogram often showed both n- and p-like surface behavior, separated by a minimum in conductance. Behavior was substantially the same in ambients of dry oxygen or nitrogen or in vacuum of 10^{-3} mm. Large changes with ozone or water vapor ambients were consistent with the Brattain-Bardeen observations on contact potential.[1] Phase-shift loops, observed at the higher frequencies in the minority carrier portions of the curves, can be interpreted in terms of minority carrier lifetime. Somewhat similar loops, observed at all frequencies in the low-temperature range, could be suppressed by illumination, and are believed to be due to traps.

[1] W. H. Brattain and J. Bardeen, Bell System Tech. J. **32**, 1–41 (1953).

Z3. Conductance of *P*-Type Inversion Layers on *n*-Type Germanium.* G. DEMARS, H. STATZ, AND L. DAVIS, JR., *Raytheon Manufacturing Company.*—Inversion layers on 8 ohm-cm n-type germanium were produced by exposing the germanium surface to a mixture of oxygen, ozone, and water vapor. The conductance was greater, the longer the sample had been exposed to the wet O_3 and O_2. Steady-state conductance was measured as a function of bias voltage. The curves were analyzed using the mobility for holes in an inversion layer as calculated by Schrieffer.[1] The calculations were carried through numerically using almost no approximations. For each conductance versus bias voltage curve, the *quasi*-Fermi level at the surface had an approximately constant position with respect to the bands. This was due to a high total density of surface states.

* This work was supported in part by the Signal Corps.
[1] J. R. Schrieffer, Phys. Rev. **54**, 1420 (1954).

Z4. Nonsteady State Conductance of Inversion Layers and the Structure of Surface States on Germanium.* H. Statz, L. Davis, Jr., and G. deMars, *Raytheon Manufacturing Company.*—The conductance of p-type inversion layers on germanium was measured as a function of bias voltage. A time dependence of the conductance was observed for abrupt changes of the voltage, the dependence being approximately of the form $\exp(-t/\tau)$. Furthermore, τ was itself a function of conductance and bias voltage, varying from a few seconds to a few minutes. The change in conductance resulted from a slow transfer of electrons from the germanium to surface states outside the germanium oxide film when the bias was changed. Other states at the germanium-germanium oxide interface had a time constant much shorter—presumably of the order of the lifetime of minority carriers. The widely different time constants were used to determine the density and energy levels of the latter states. Conductance measurements were made in sufficiently short time intervals that the charge in the states outside the germanium oxide was constant. Accurate analysis of the curves so obtained gave one energy level at the surface 0.155 ev below the middle of the band with a density of from 7×10^{10} to 1.2×10^{11} states/cm^2.

* This work was supported in part by the Signal Corps.

Z5. Surface-Recombination Velocity and Surface Conductance of Thin Germanium Slabs.* Donald T. Stevenson, *M. I. T.*—The approximate position of the Fermi level at germanium surfaces can be deduced from the changes of surface conductance with gaseous ambient. Simultaneous measurements of surface conductance and surface recombination velocity have been made in oxygen and nitrogen of varying humidity in order to test a previous theory[1]. Preliminary work indicates that this simple theory based on a single trapping level at the surface is not sufficient to explain the measurements. The recombination velocity on etched intrinsic and n-type samples is always lower in dry ambient than in wet. Conductance changes with humidity on sandblasted samples and etched samples are nearly the same indicating that the change in Fermi level is about the same in both cases. From previous experiments it is known that the recombination velocity at sandblasted surfaces is greater than 10^4 cm/sec, while on the etched surfaces studies here it was of the order of 50 cm/sec. It would appear that at least two sets of levels are required. The levels responsible for maintaining the charge balance are not affected appreciably by sandblasting.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

[1] D. T. Stevenson and R. J. Keyes, Physica (to be published).

Z6. Photomultiplication at the Surface of Germanium.* H. Bernstein and R. H. Kingston, *M. I. T.*—Photomultiplication has been observed at the surface of p-type germanium in a wet nitrogen ambient. If an $n-p-n$-grown junction bar is canned with a chopped light source, the photoresponse in the p-type region is found to increase when the reverse bias is increased beyond a particluar value. In a dry-nitrogen ambient however, photomultiplication is not observed below a much higher bias which is near the avalanche breakdown voltage of the bulk junction.[1] It is proposed that this phenomenon may be explained in terms of the expected high field between the bulk and the n-type inversion layer or "channel" induced by the moist ambient.[2,3]

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

[1] K. G. McKay, Phys. Rev. **94**, 877 (1954).
[2] W. L. Brown, Phys. Rev. **91**, 518 (1953).
[3] A. L. McWhorter and R. H. Kingston, Proc. Inst. Radio Engrs. **42**, 1376 (1954).

Z7. Oxidation of Clean Surfaces of Germanium Below 25°C.* Mino Green and J. A. Kafalas, *M. I. T.*—The oxidation of clean surfaces of germanium in wet and dry oxygen has been studied in the temperature range −68°C to +25°C and the oxygen pressure range 1 to 200 microns. Fresh surfaces were obtained by crushing the germanium in an all-glass system in the presence of the gas to be adsorbed. The uptake of oxygen was not affected by the presence of water vapor. The oxygen uptake was approximately 3 oxygen atoms per surface germanium atom at 25°C, and was 10 percent less at −68°C. There was no appreciable difference in the extent of oxidation between n- and p-type germanium. Complete oxygen uptake occurred in <5 seconds over the pressure range investigated.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

Z8. Effect of Dislocations on Recombination of Holes and Electrons in Germanium and Silicon.* S. A. Kulin, A. D. Kurtz, and B. L. Averbach, *M. I. T.*—Experimental data indicate that edge-type dislocations markedly affect the recombination rate of holes and electrons in germanium and silicon. Dislocation densities have been measured by x-ray methods and the results correlated with the lifetime of minority carriers. In germanium results were obtained for three resistivity ranges. These results show that variations in the dislocation density at constant resistivity cause large changes in lifetime, the lifetime being inversely proportional to the dislocation density. Similar results have been obtained using silicon of a single resistivity range. Assuming each dislocation acts as a recombination center, a quantity σ_R, which relates to the recombination efficiency per unit length of dislocation, may be determined. Measurements on silicon specimens yield the value of $\sigma_R \cong 1.7\times10^{-8}$ cm^{-1} sec^{-1} compared with a value of $\sigma_R \cong 3.5\times10^{-3}$ cm^{-1} sec^{-1} for germanium. This difference is explained in terms of the larger energy-band perturbations caused by dislocations in silicon. These measurements indicate that individual dislocations are inherently more efficient recombination centers in silicon than in germanium.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

Z9. Recombination of Injected Carriers at Dislocation Edges in Semiconductors. J. P. McKelvey and R. L. Longini, *Westinghouse Research Laboratories.*—The boundary conditions on the continuity equation for carrier recombination at a lineage boundary in a semiconductor in the presence of an applied electric field are derived from kinetic considerations. A nonrecombination probability or "transmission coefficient" for a single charge carrier is assumed initially, and the boundary conditions are obtained by the method of multiple reflections which has heretofore been used to analyze surface recombination.[1] The carrier concentration at the boundary is in general discontinuous, the concentrations on either side involving the transmission coefficient, the bulk lifetime, the concentration gradients, the drift velocity, and the mean free path. The ratios of the concentration gradient to the concentration are independent of the concentrations on either side of the boundary and are functions of the drift velocity, the bulk lifetime and, in one case only, of the transmission coefficient. A simple experiment to determine the transmission coefficient is suggested; the continuity equation can be solved for this case. The relationship between transmission coefficient and recombination cross section is derived, permitting one to calculate the actual cross section for a single dislocation if the dislocation density in the lineage line is known.

[1] J. P. McKelvey and R. L. Longini, J. Appl. Phys. **25**, 634 (1954).

Z10. Bond Dipoles and Piezoelectricity in Zincblende Semiconductors. JOSEPH L. BIRMAN, *Sylvania Electric Products Inc.*—A. von Hippel[1] has recently reemphasized the view[2] that an acentric dipolar array is responsible for the piezoelectric effect. Hence, on symmetry grounds alone all substances crystallizing in the zincblende structure can be expected to exhibit this effect. The present paper is an attempt to make this view quantitative and to calculate the magnitude of the bond dipole moment from the measured piezoelectric constant. It is assumed (1) that each chemical bond is characterized by a vector bond dipole moment directed along the bond, whose magnitude varies linearly with bond length; (2) that the polarization is to be obtained by summing the individual bond dipole vectors; (3) that infinitesimal lattice-elasticity theory applies. The basic equation of piezoelectricity in the zincblende structure is thereby derived. This equation relates initial-bond moment, change in moment with bond length, internal strains, and external (elastic) strains, to the piezopolarization. The equation will be discussed and compared with other recent work.[3]

[1] A. von Hippel, Z. Physik, 133, 158 (1952).
[2] E. Riecke, Abh. Akad. Wiss. Göttingen 38, (1892); W. Voigt, Abh. Akad. Wiss. Göttingen 36, (1890).
[3] B. D. Saksena, Phys. Rev. 81, 1012 (1951). He has neglected the internal strains and the changes in bond angle under strain.

Z11. Electrical Conductivity of Liquid Tellurium.* V. A. JOHNSON, *Purdue University.*—Experiments show that liquid selenium, when pure, behaves as an ideal semiconductor[1] and that liquid germanium has a metallic behavior.[2] Measurements on liquid tellurium[3] indicate a behavior intermediate between that of selenium and germanium, a transition with rising temperature from semiconductor to metallic state. An analysis of conductivity *vs* reciprocal temperature curves for eight liquid-tellurium samples indicates that (1) the slope at the melting point corresponds to the forbidden band width of solid tellurium, (2) above the melting point the measured conductivity can be represented by $(1-f)\sigma_{sc}+f\sigma_m$, where f is a Boltzmann factor $e^{-W/kT}$. σ_{sc} is found from $\sigma_0 \exp(-E_0/2kT)$ with σ_0 determined by the melting point conductivity, and $\sigma_m = A/T$ with A found from the conductivity maximum, and (3) the energy W of the Boltzmann factor is approximately $(0.48-4.8\times10^{-4}T)$ev. One can hypothesize that the change from semiconductor to metallic behavior in tellurium is due to the release of free electrons by the dissociation of the chain structure.

* Work assisted by Signal Corps Contract.
[1] H. W. Henkels, J. Appl. Phys. 21, 725 (1950).
[2] A. S. Epstein, Ph.D. Thesis, Purdue University (1954).
[3] A. Epstein and H. Fritzsche, Phys. Rev. 93, 922; 94, 1426 (1954).

Z12. Noise in Silicon *p-n* Junction Photocells. G. L. PEARSON, H. C. MONTGOMERY, AND W. L. FELDMANN, *Bell Telephone Laboratories.*—The noise in silicon $p-n$ junction photocells prepared by the gaseous diffusion method[1] has been measured as a function of current and frequency. Under reverse bias conditions it is found that the noise is composed entirely of shot contributions and that the spectrum is white above 70 cps. This is in contrast to other semiconductor devices where larger dark currents contribute an additional $1/f$ spectrum.[2] The theoretical relation for shot noise is $\langle I_s^2\rangle_{\Delta f} = 2eiF$ where e is the electronic charge, i the dc current, and F the frequency band. Precise shot measurements on a typical cell in a frequency band from 700 to 900 cps gave 1.62×10^{-19} coulombs for the electronic charge at currents between 10 and 200 microamperes. When used as a photovoltaic device the shot noise is reduced markedly, and this is attributed to the existing space charge.

[1] C. S. Fuller and J. A. Ditzenberger, J. Appl. Phys. 25, 1439 (1954).
[2] H. C. Montgomery and M. A. Clarke, J. Appl. Phys. 24, 1337 (1953).

Z13. Excess Noise and Trapping in Germanium.* H. A. GEBBIE, *M. I. T.*—The frequency dependence of excess noise in specimens of 10 ohm-cm n-type germanium has been measured at temperatures from 100°K to 300°K. The frequency was from 10 cps to 16 Kcps. At 300°K the spectra of all specimens could be represented by the addition of $1/f$ noise and shot noise with a characteristic time equal to the free-hole lifetime. At temperatures about 200°K however, some specimens showed spectra of the same form but the characteristic time of the shot noise was much greater than the free-hole lifetime. This characteristic time increased rapidly with decreasing temperature. In these cases it is suggested that the shot noise is due to trapping. This is supported by the observation that photoconductivity in these specimens increased rapidly with decreasing temperature. The noise spectra at lower temperatures were more complex. Other specimens showed spectra with no measurable shot-noise component at low temperatures. In these cases no trapping was indicated by the photoconductivity.

* The research in this document was supported jointly by the Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.

Z14. Noise Measurements in Semiconductors at Very Low Frequencies. T. E. FIRLE AND H. WINSTON.—The low-frequency noise spectra of germanium and silicon rectifiers have been determined. Two methods were employed: a numerical analysis according to the Wiener-Khintchine relationship and a frequency translation photo play-back method. No evidence of a deviation from a $1/f^a (a>1)$ noise-power law was found down to frequencies as low as 6×10^{-5} cps.

Z15. Elastic Strain Energy Stored in Mechanically Disturbed Surfaces. R. L. HOPKINS, *Sylvania Electric Products Inc.*—During a study of the electrical properties of mechanically disturbed germanium[1] it was found that thin slabs of germanium and other materials (Ge, Fe, Ni, and Cu are to be reported on) bend in an elastic manner when sandblasted on one of their two major surfaces. The mechanical disturbance caused by such sandblasting is determined by a chemical-etching technique to extend to a depth, α, which depends on the material. This bending is attributed to stresses exerted in the mechanically disturbed region which correspond to elastic strain energy stored during the blasting process. The magnitude of this energy is estimated by a method to be described, the results being compared to a model suggesting that large concentrations of edge dislocations are produced during sandblasting.

[1] E. N. Clarke and R. L. Hopkins, Phys. Rev. 91, 1566 (1953); samples reported here were thick enough so that appreciable bending did not occur.

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